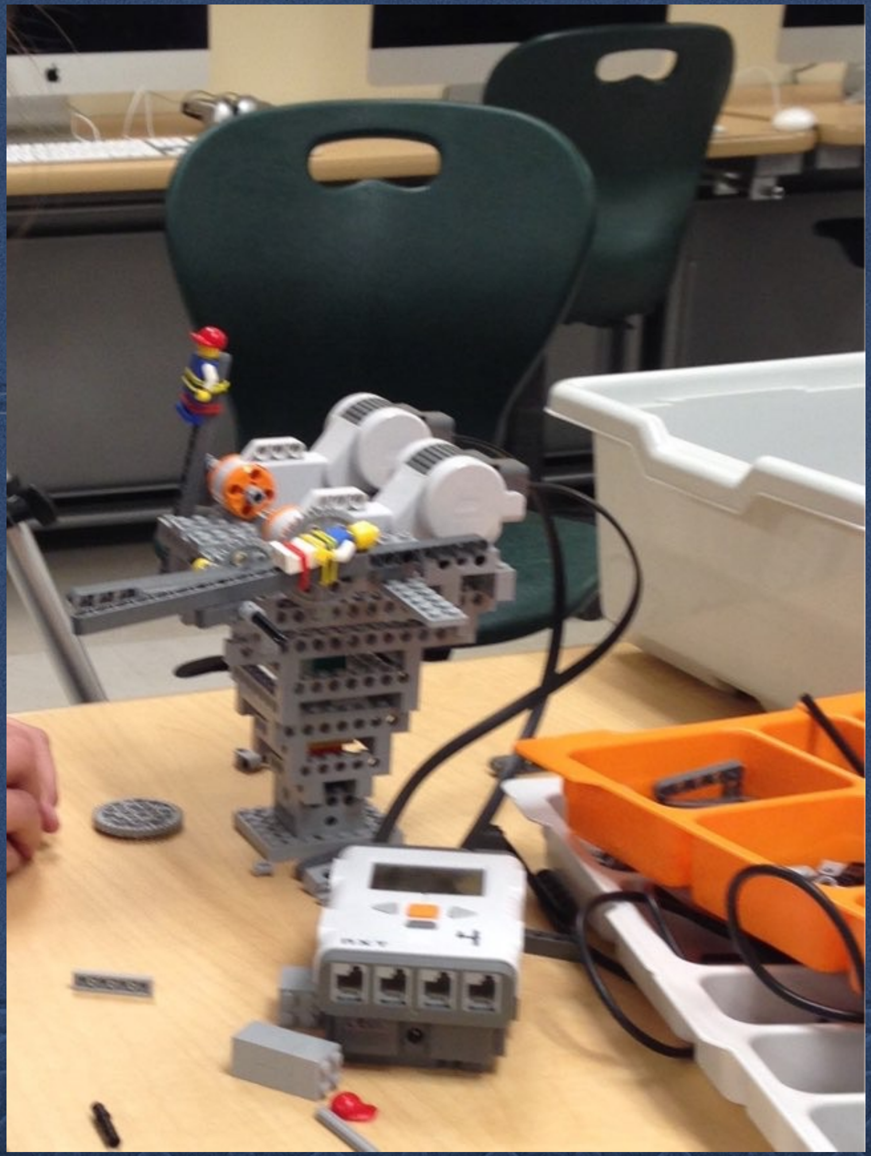
Cross Case Study of Elementary Engineering Task



John Heffernan, Ph.D. - kidsengineer.com

Problem Statement

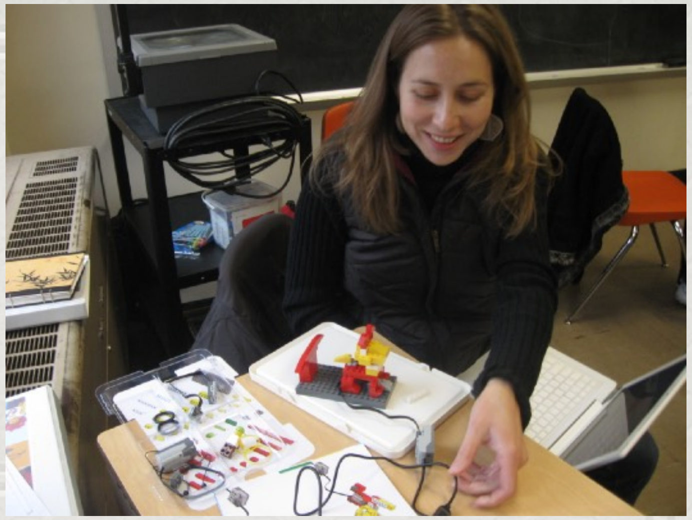
- *Increasing academic focus resulting in loss of designerly play including engineering (Zhao, 2012).*
- *High need for diverse STEM workforce (Brophy, Portsmore, Klein, & Rogers, 2008).*
- *Start at elementary (Cunningham & Hester, 2007)*
  - *Children natural builders*
  - *Motivating, increase STEM pipeline*
  - *Integrate math and science*
  - *Problems solving, modeling, collaboration*

Background

- *EE/CS Major - liked ELA best, Tufts*
- *Worked at RCA and DEC for 10 years*
- *Running, juggling, and kids*
- *Became grade 3 teacher*
- *Ed tech consultant, tech teacher, robotics*

- *Ph.D. dream (missed change with CS Unplugged, not w/ robotics)*

Robotics Experience



- *Started with grade 6 RCX*
- *Loved the engineering, loved the social-emotional, motivation, problem-solving*
- *Excited when WeDo 1 came out - came up with K-6 curriculum - some LEGO WeDo plus my BeeBot, my WeDo and NXT open-ended*
- *Got NXT and WeDo grants for local districts, did local PD and consulting*
- *So much going on: how best to teach, what is going on developmentally, cognitively?*
- *Started extensive reading before and during Ph.D. program, led in many different directions (many dead ends and non-relevant info)*
- *Started teacher action and pilot studies, started Ph.D. program*

What Is Known Already? Design and STEM

- *Engineering design experiences including robotics, given sufficient time (Williams, Ma, Lai, Prejean, & Ford, 2007) and appropriate pedagogy (Sullivan, 2008) result in STEM content and process skills increases and STEM interest and self-efficacy gains*
- *Worth studying*

What Is Known Already? Design and Science

- *Expert designers apply science more than novice designers (Crismond, 2001)*
- *Design based science creates affordances for the application and understanding of science concepts and practices but only with teacher scaffolding (Fortus et al., 2005; Leonard & Derry, 2011; Mitnik et al., 2009; Puntambekar & Kolodner, 2005; Atman et al., 2007)*
- *Ok, teachers important*

Designerly Play

- *The elements of design that are found in children's play*
- *A fundamental component of childhood (Baynes, 1994; Petroski, 2003)*
- *Children "actively seek engagement with their surroundings" and "desire to interact and shape the environment" (Baynes, 1994, p. 12)*

What Is Known Already? Designerly Play

- *Children come to school with natural experience and processes in place for design (Outterside, 1993)*
- *11 year olds still engaged in fantasy play in a design task but in a more subdued and socially acceptable way than 5 year olds (Fleer, 1999)*
- *Robots have particular efficacy for creativity due to the nature of robotics (Slangen, Keulen, & Gravemeijer, 2010; Levy & Mioduser, 2008; Mioduser, Levy, & Talis, 2007)*

Executive Function

- *Typically defined as "a collection of inter-related processes responsible for purposeful, goal-directed behavior," such as "anticipation, goal selection, planning, initiation of activity, self-regulation, mental flexibility, deployment of attention, and utilization of feedback" (Davidson, Amso, Anderson, & Diamond, 2006, p. 71).*
- *Most relevant to open-ended engineering design problems: cognitive flexibility, planning, and causal reasoning*

Cognitive Flexibility

- *Saw "non-optimal persistence" in pilot study*
- *Cognitive flexibility - "the ability to consider multiple bits of information or ideas at one time and actively switch between them when engaging in a task" (Cartwright, 2012, p. 26), more generally flexible thinking*
- *Developmental (Cartwright, 2012; Davidson et al., 2006)*
- *Needed for ill-structured problems (Cutting et al., 2011) or to invent new things (Sternberg, 2003; Stone-Macdonald et al., 2015)*

Cognitive Flexibility - Tool Innovation

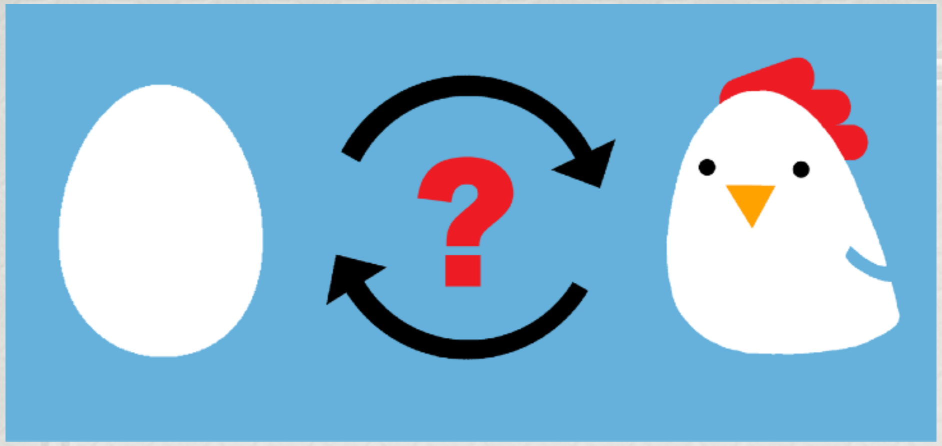
- *“It seems plausible that difficulty in switching between alternatives might contribute to children’s difficulty with tool innovation" (Cutting et al., 2011, p. 499).*
- *Perseveration (or non-optimal persistence), though seen, was not a statistically significant factor in the first experiment and that success on on task did not cause problems with a second, "opposite" task.*
- *However, the four and five year olds did show significant levels of task perseverance as compared to six and seven year olds in the second experiment*

Structural Knowledge and Tool Innovation

- *Older children able to integrate the domain knowledge but younger children were not, even when both pieces of required domain specific knowledge was highlighted for them (Cutting et al., 2011, p. 499)*
- *Cutting et al. conclude that, "that without this structural knowledge, young children lacked the flexibility needed to retrieve their knowledge from memory and then coordinate it in order to solve these tool innovation tasks" (Cutting, Apperly, Chappell, & Beck, 2014, p. 115).*

Planning

- *Some positive results were found in G1 students with tightly constrained problems and familiar materials (Portsmore & Brizuela, 2011)*
- *Other studies find that young students largely skip the planning phase due to developmental constraints (Anning, 1994; Fleer, 1999)*
- *Planning may not be as effective in the more general case of open-ended engineering challenges where knowledge transfer must occur*



Causal Reasoning

- *Inference and prediction critical for engineers*
- *"You have to think in a different way. This would make this - would make this - happen. Each step is connected", Grade 4 Student*

Casual Reasoning

- *Elementary robotics curriculum and instruction should teach both data based and mechanism based approaches to troubleshooting (Kuhn & Dean, 2004)*
- *Curriculum needed to help students apply control of variables and other scientific reasoning skills such as systemic testing, systems thinking (Kuhn, 2007, Sullivan 2008)*
- *The development of scientific (hence causal) reasoning is gradual, continuous, and not a discrete developmental milestone like Piagetian conservation (Kuhn et al., 1992)*

Robotics and Gender

- *Important factors for the lower self-efficacy of females and the achievement differences: stereotype threat, teacher differences in their treatment of boys and girls, the lack of acceptance of epistemological pluralism, and lack of previous experience*
- *How do these factors operate in the context of a K-6 elementary engineering curriculum?*

Frameworks Examined

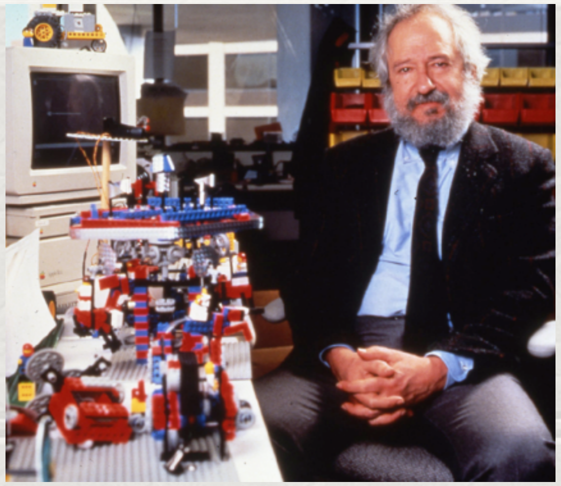
- *Overall theoretical lenses to view cognitive or other processes related to design*
- *Might explain cognition and EDP in elementary engineering based on robotics*

Piagetian Constructivism

- *Children construct their knowledge*
- *Defines 4 universal, discrete stages of development (Piaget & Inhelder, 1969)*
    - *sensorimotor (0 to 2)*
    - *pre-operational (2 to 7)*
    - *concrete operational (7 to 11)*
    - *formal operational (11 and up)*

Neo-Piagetian Constructivism

- *Research showed wide individual variation in the stages and cognitive structures Piaget described were not as universal as Piaget had claimed (Bidell & Fischer, 1992; Case, 1991; Young, 2011)*
- *Executive control structures and domain specific structures (Case, 1991)*



Constructionism

- *Constructionism--the N word as opposed to the V word--shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe. (Harel, 1991, p. 1)*
- *Theoretical basis for educational robotics (Papert, 2000; Papert & Harel, 1991).*

Existing Research Conclusion

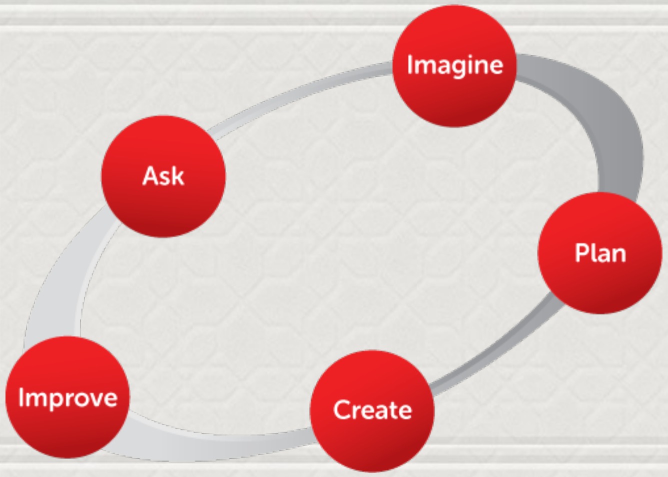
While much is known about the theory and actual design processes of older students and experts, there has not been a thorough and in-depth study of elementary student design processes and it is unknown if and how the conclusions and recommendations of these studies apply at the elementary level.

Research Questions

- *Do grade 2 and grade 6 students' engineering design processes and final products differ? If so, what are the specific differences?*
- *Do male and female students' engineering design processes and final products differ? If so, what are the specific differences?*
- *Added: if differences are not seen by gender and grade level, what relationships do explain the differing final products and engineering design processes of elementary students?*
- *First, need an EDP model for this study*

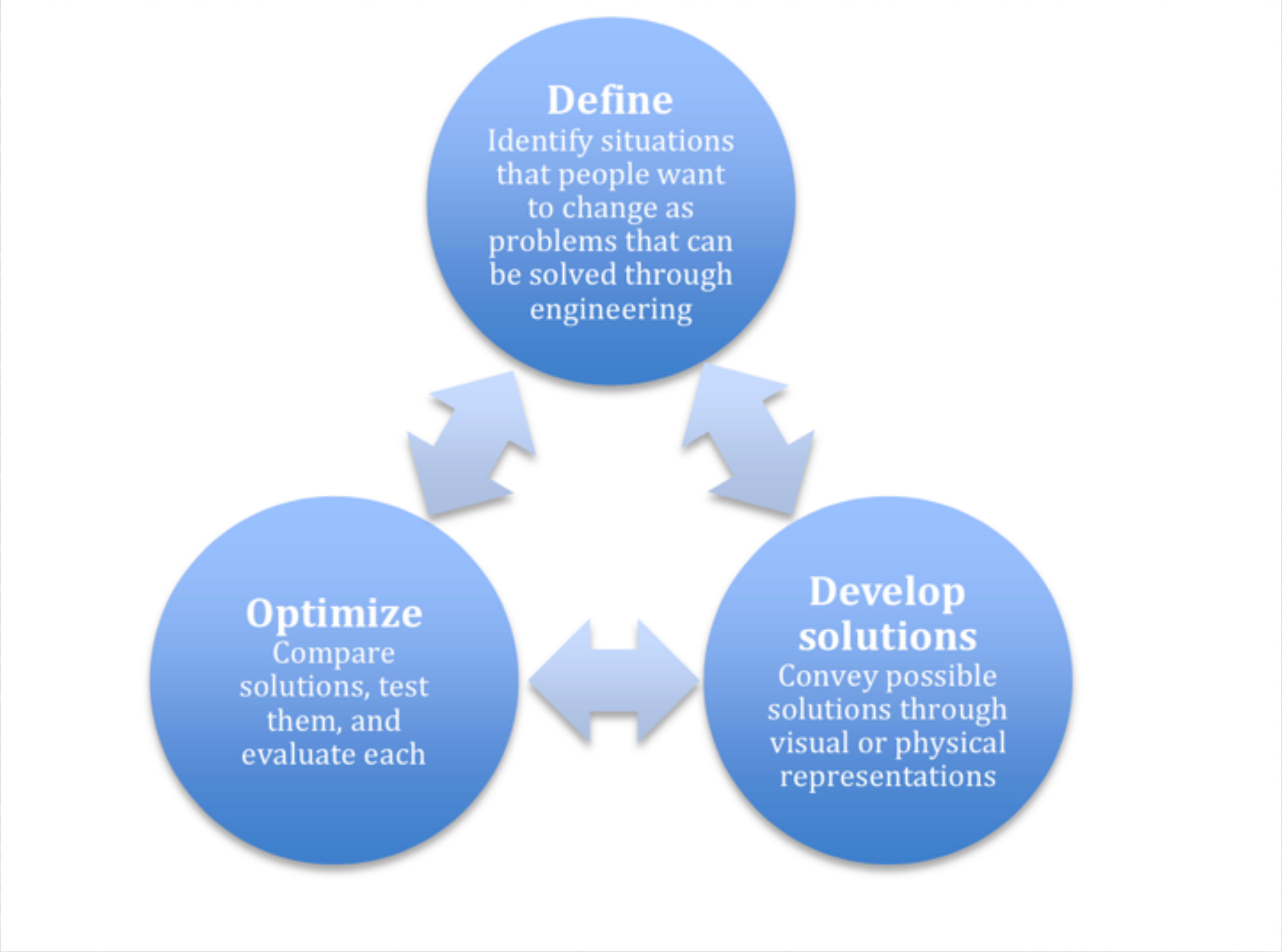
Problem Solving and EDP Models

- *Engineering one type of more general problem solving that:*
  - *uses math and science*
  - *has constraints*
  - *solves particular human need*

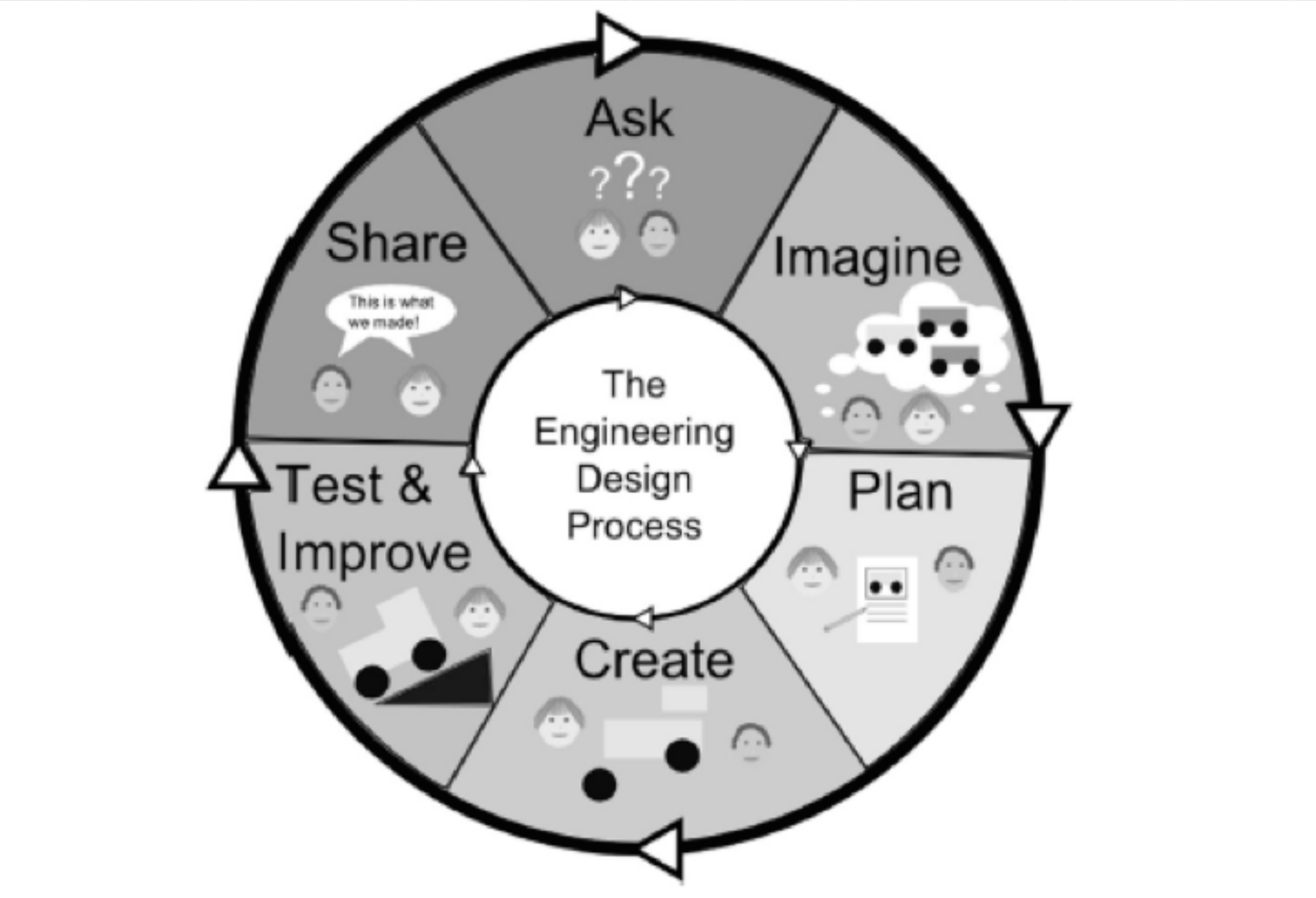


Previous Research - Design Processes

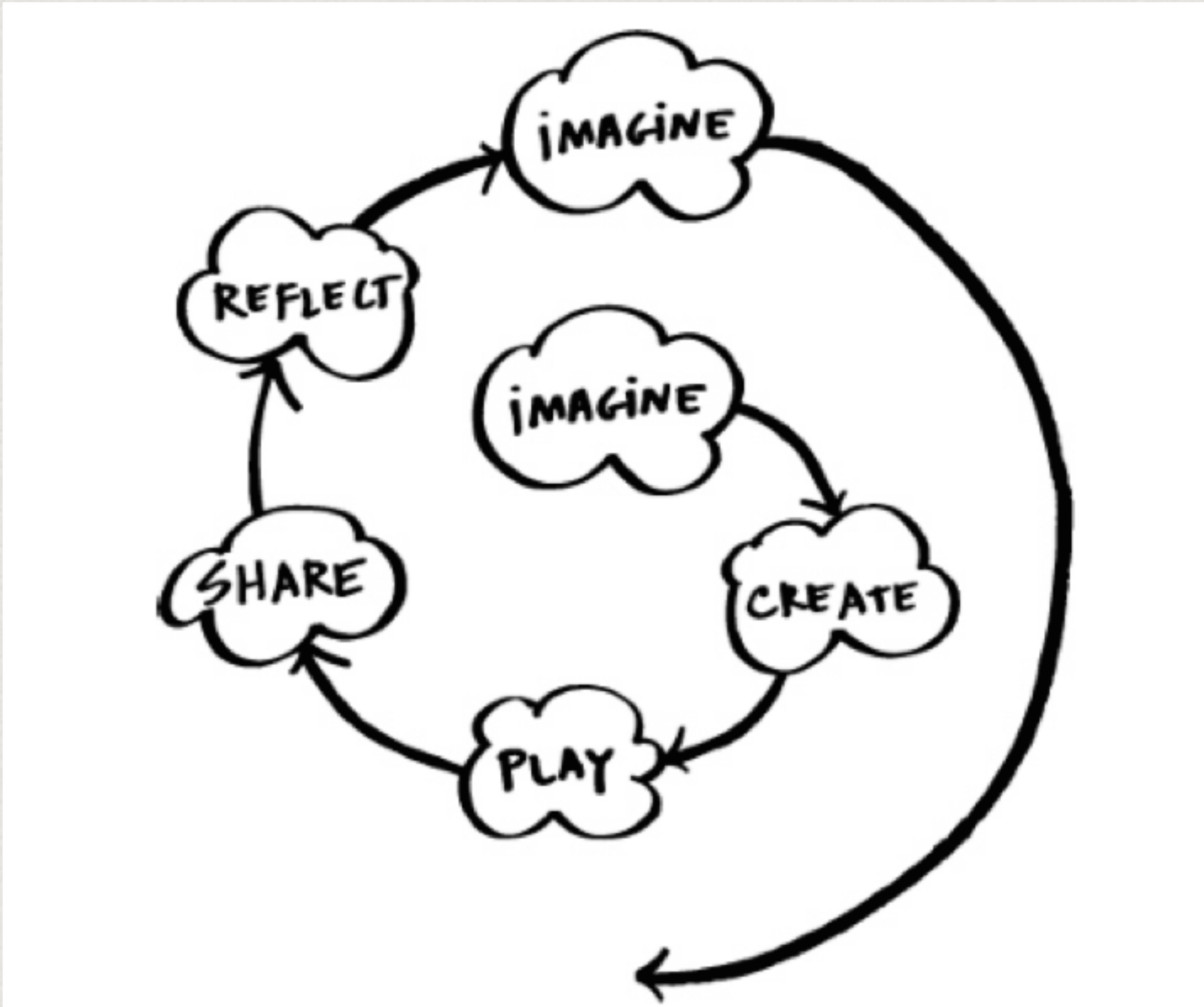
- *Actual design processes differ from theorized, idealized, linear models (Crismond, 2001; Johnsey, 1993; McRobbie et al., 2001; Welch, 1999)*
- *Experts use more content knowledge, use general design principles, and use the EDP more effectively (Cardella, Atman, Turns, & Adams, 2008; Crismond, 2001)*
- *Design skills and processes change with age and experience - development may be important (Roden 1997, 1999; Atman, Cardella, Turns, & Adams, 2005)*


Define
Identify situations that people want to change as problems that can be solved through engineering
Develop solutions
Convey possible solutions through visual or physical representations
Optimize
Compare solutions, test them, and evaluate each

NGSS (2015)

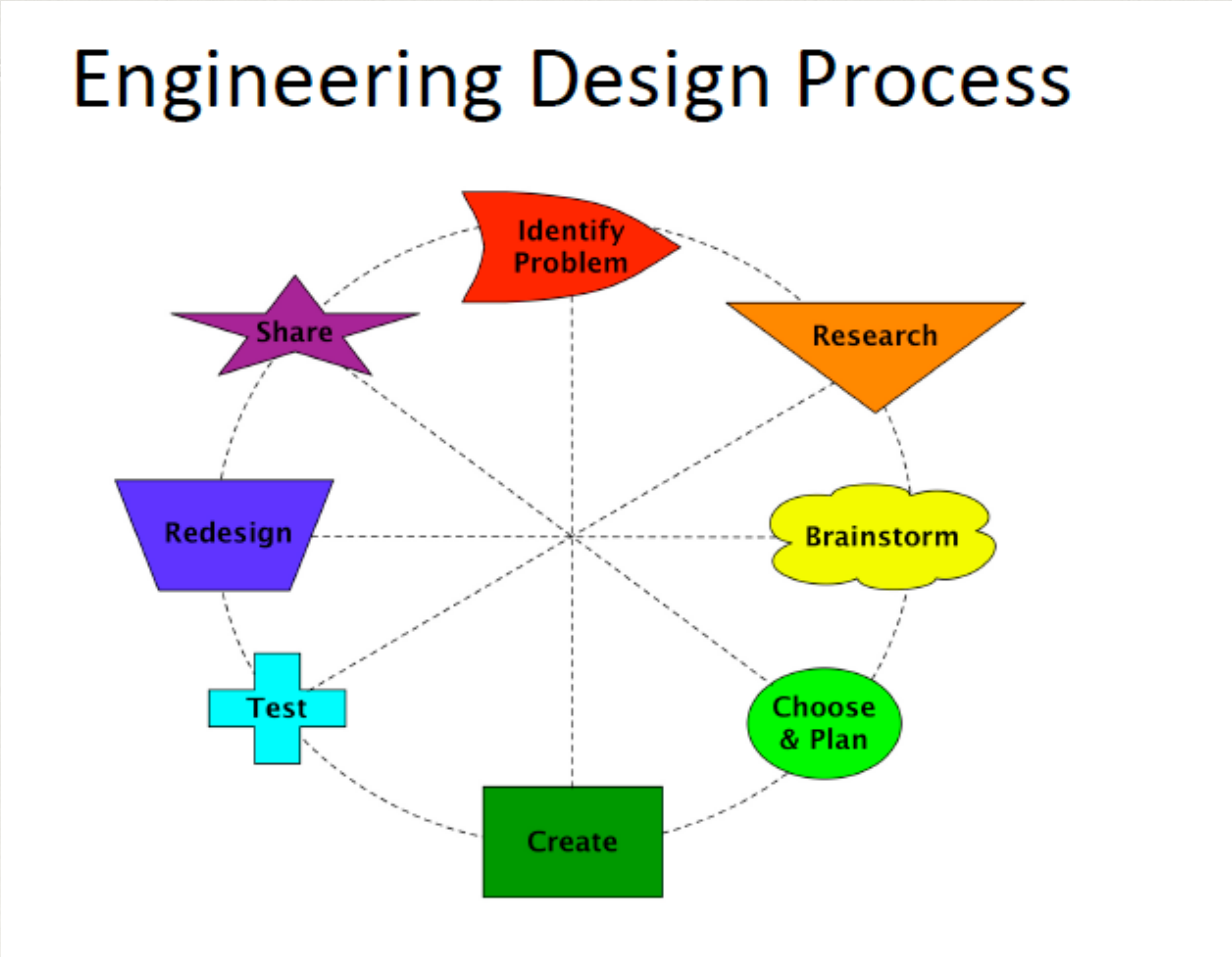


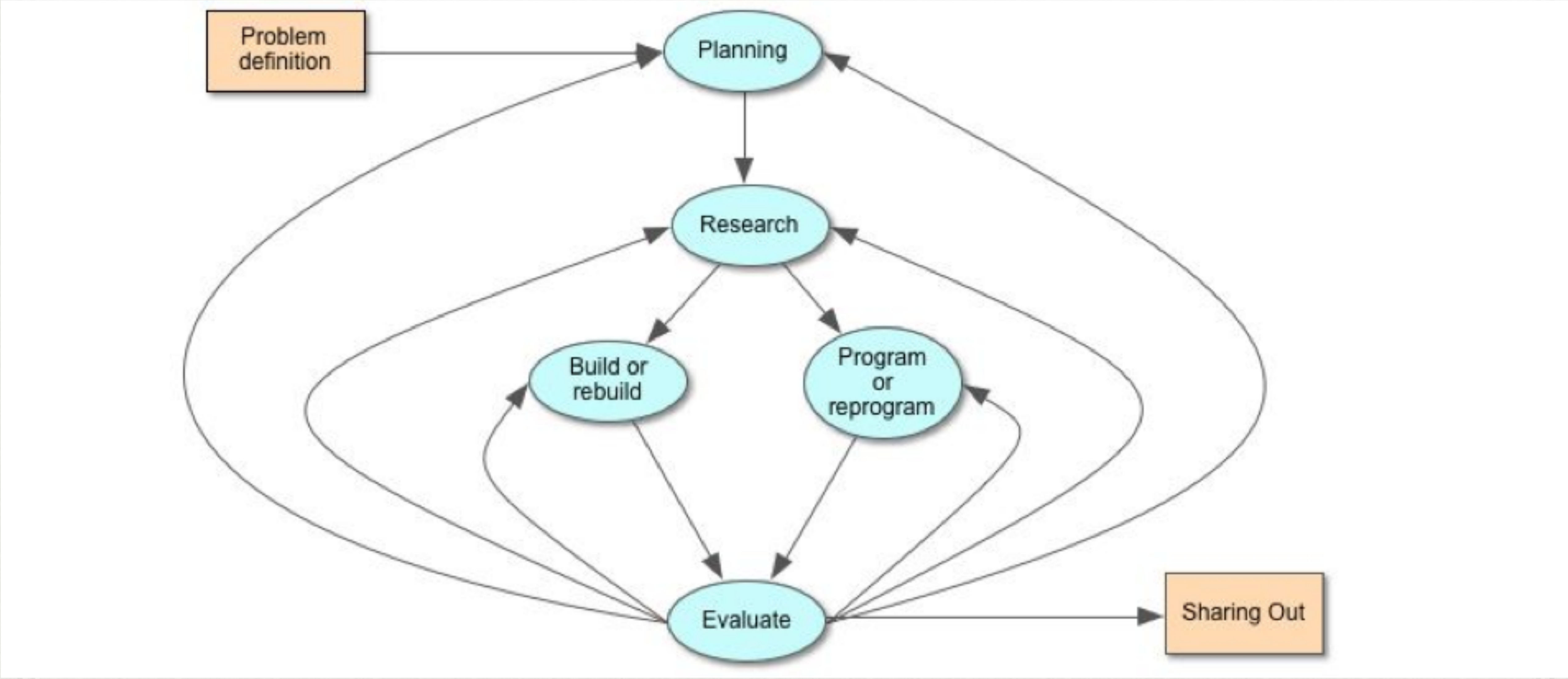
Bers, Flannery, Kazakoff, Sullivan (2014)



Resnick (2007)

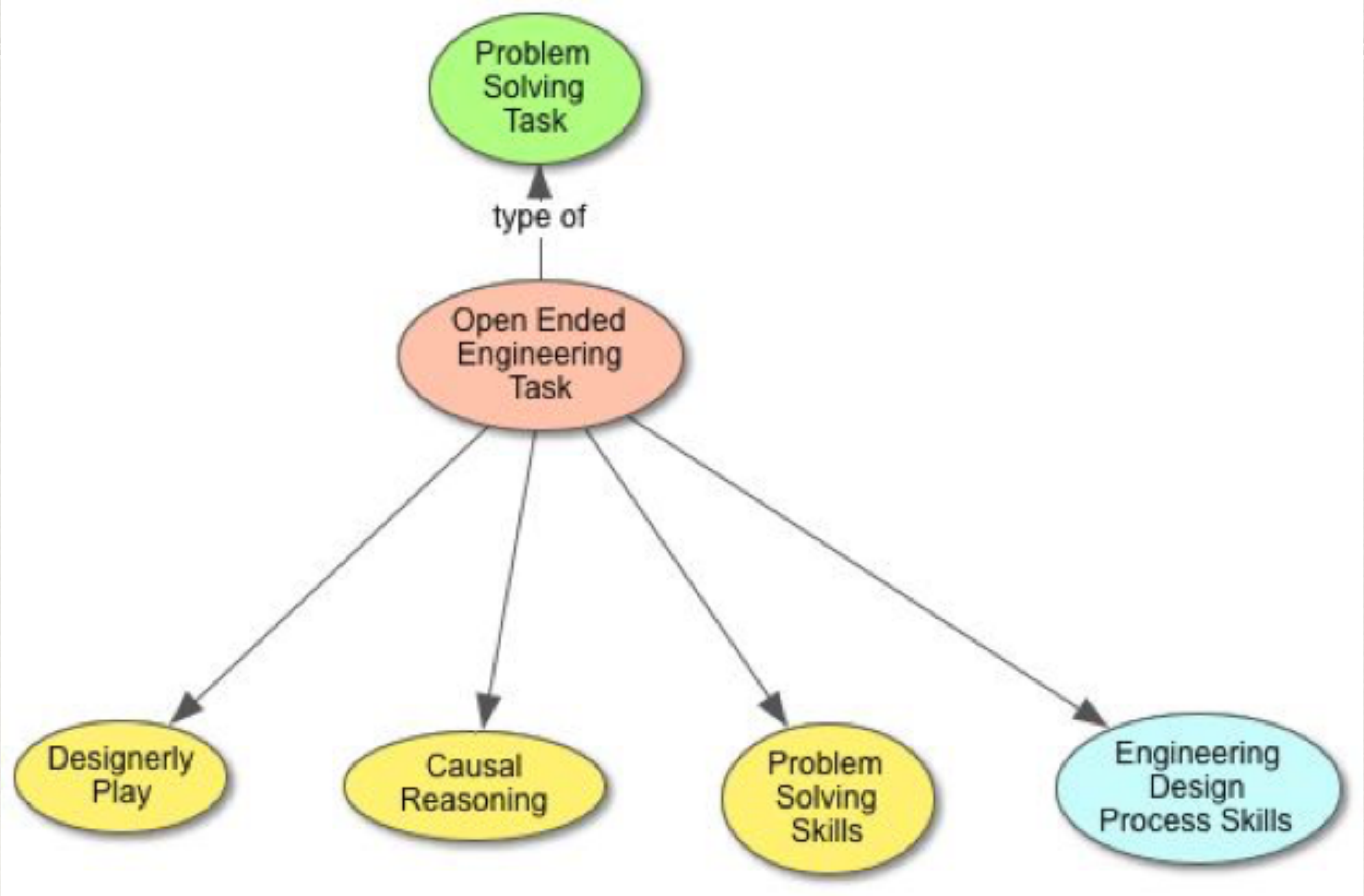
Portsmore (2011)





Engineering design process model for this study

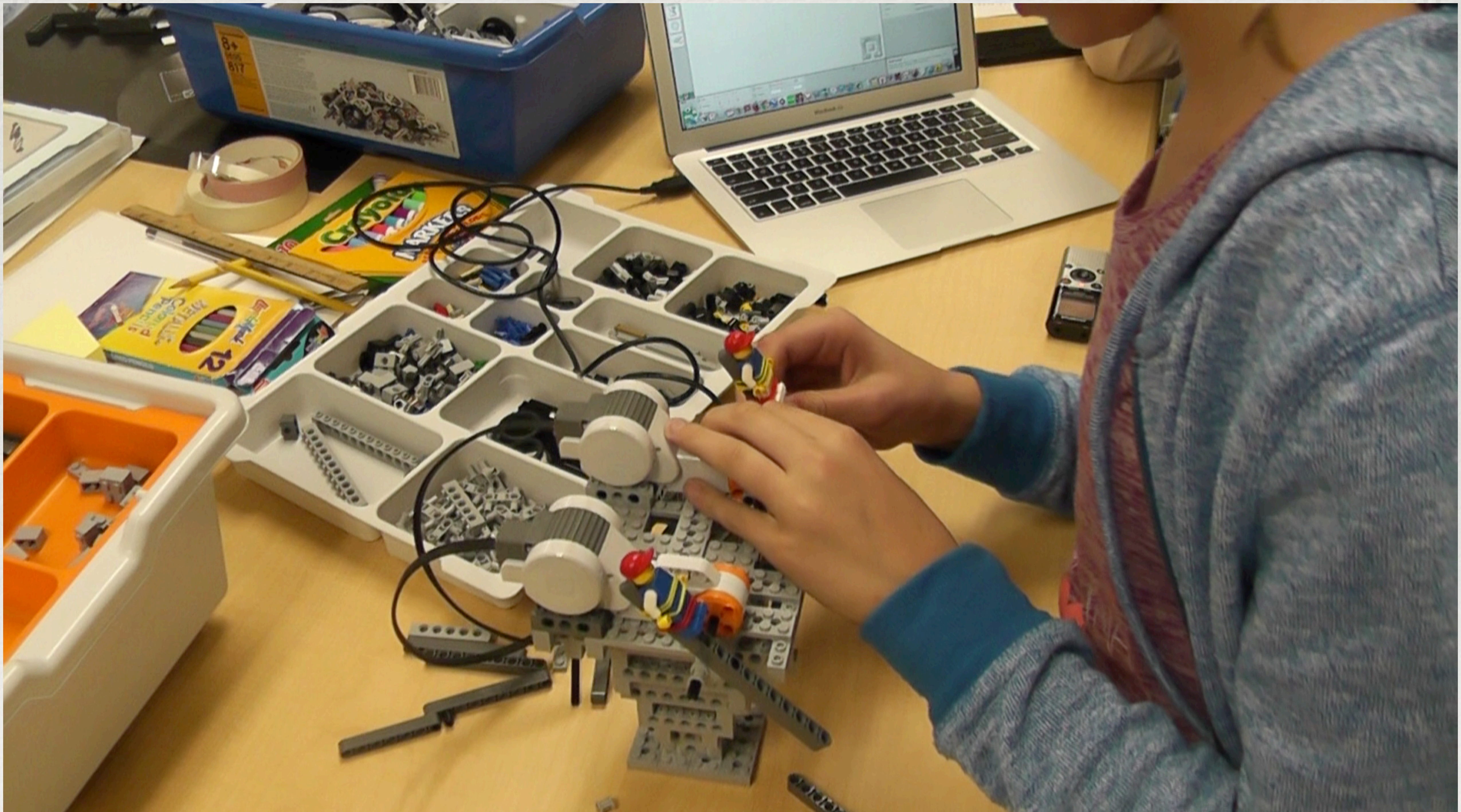
Initial Conceptual Framework



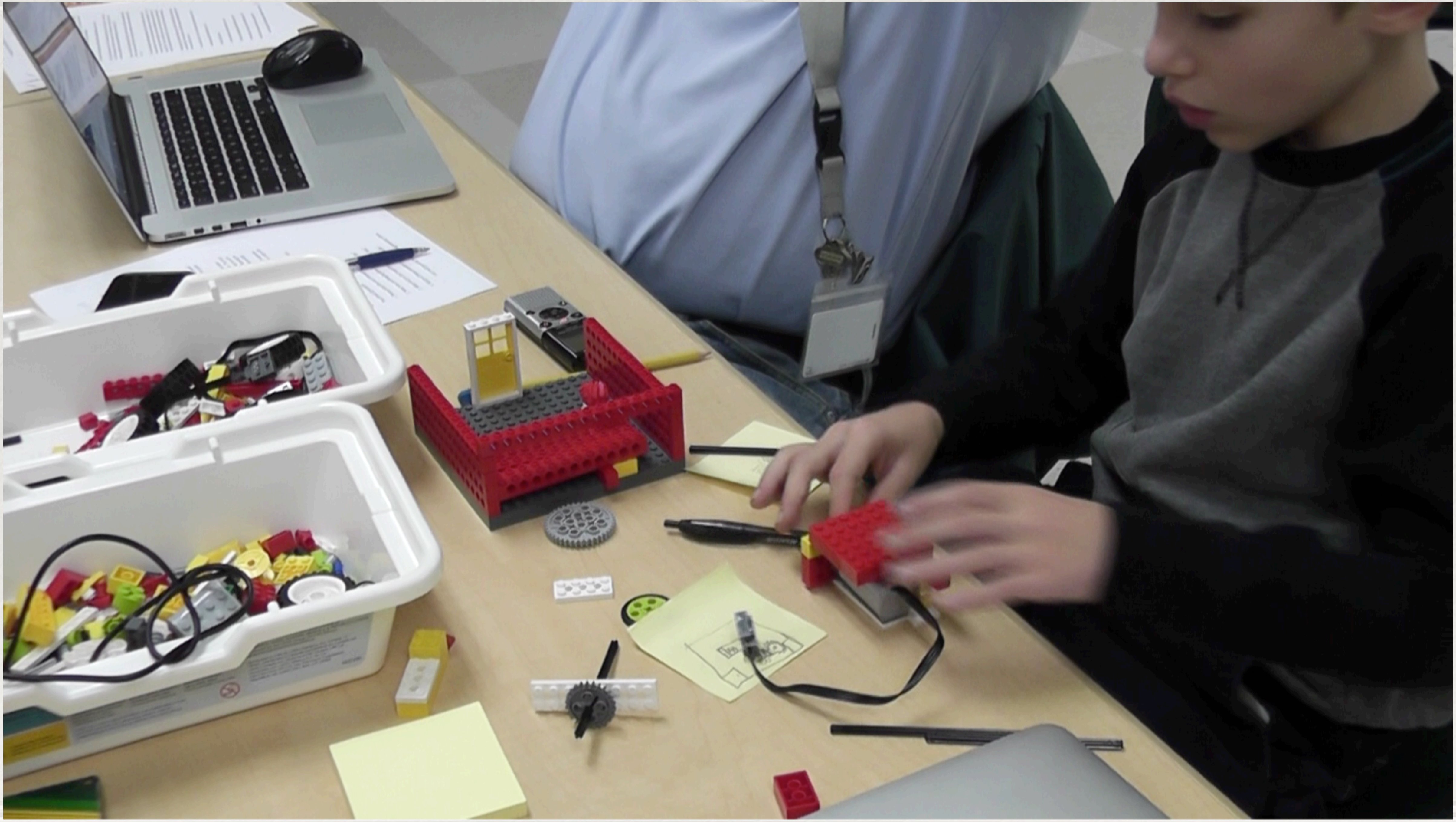
Methodology

- *Qualitative, Cross Case, Cross-Sectional*
- *Semi-clinical video interview (Ginsburg, 1997)*
- *Talk aloud protocol (Ericsson & Simon, 1980)*
- *Filmed six typical, second grade student and six typical, grade six students doing same open-ended engineering task of amusement park ride with age-appropriate LEGO robotics materials and craft materials*
- *All students started with curriculum in K*
- *Qualitative analysis of EDP, finished rides, and EDP related codes and activity*

Girl 5 Snowball Effect

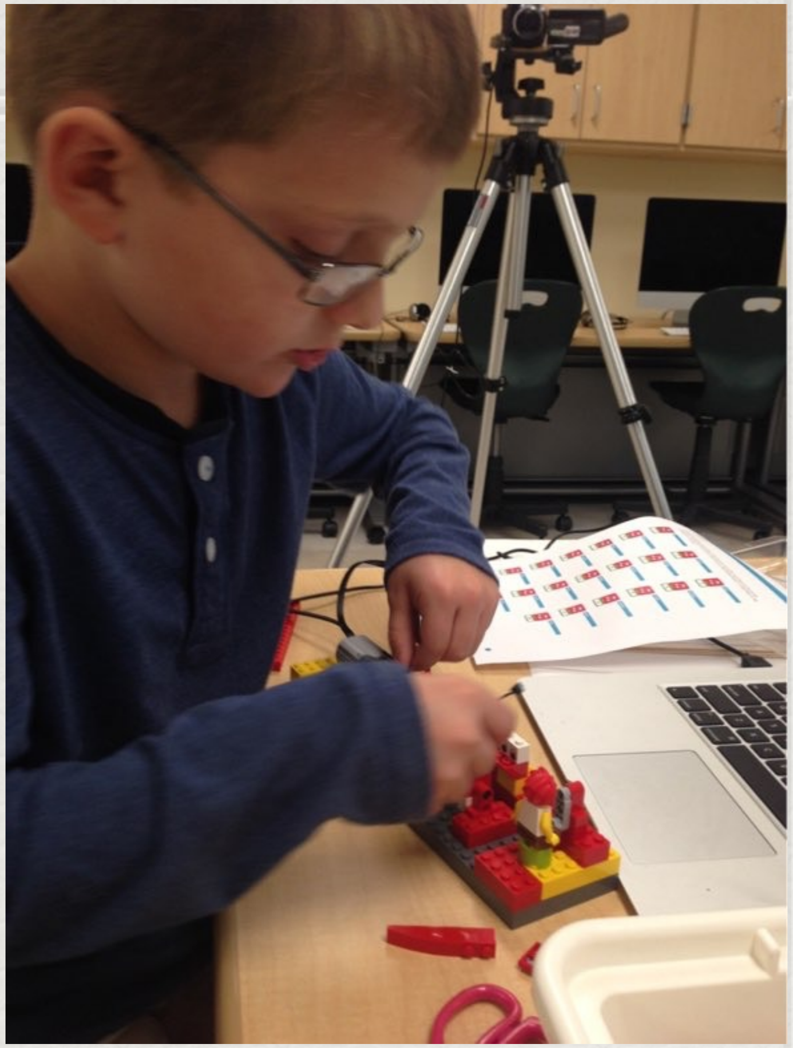


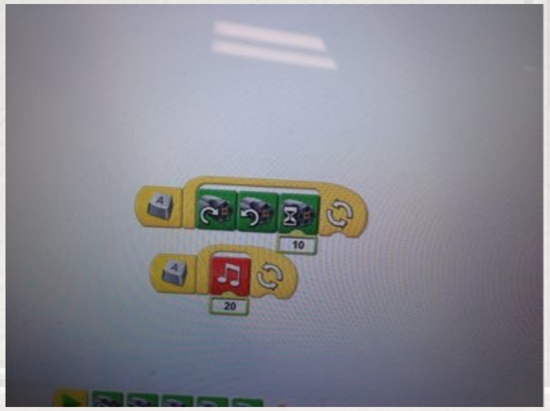
Boy 8 Learning Moment



Data Collection

- *Warm up task (roof)*
- *Programs*
- *Photos of model*
- *Design data for each finished model*
- *Video tape of sessions - yielded EDP and EDP related data*





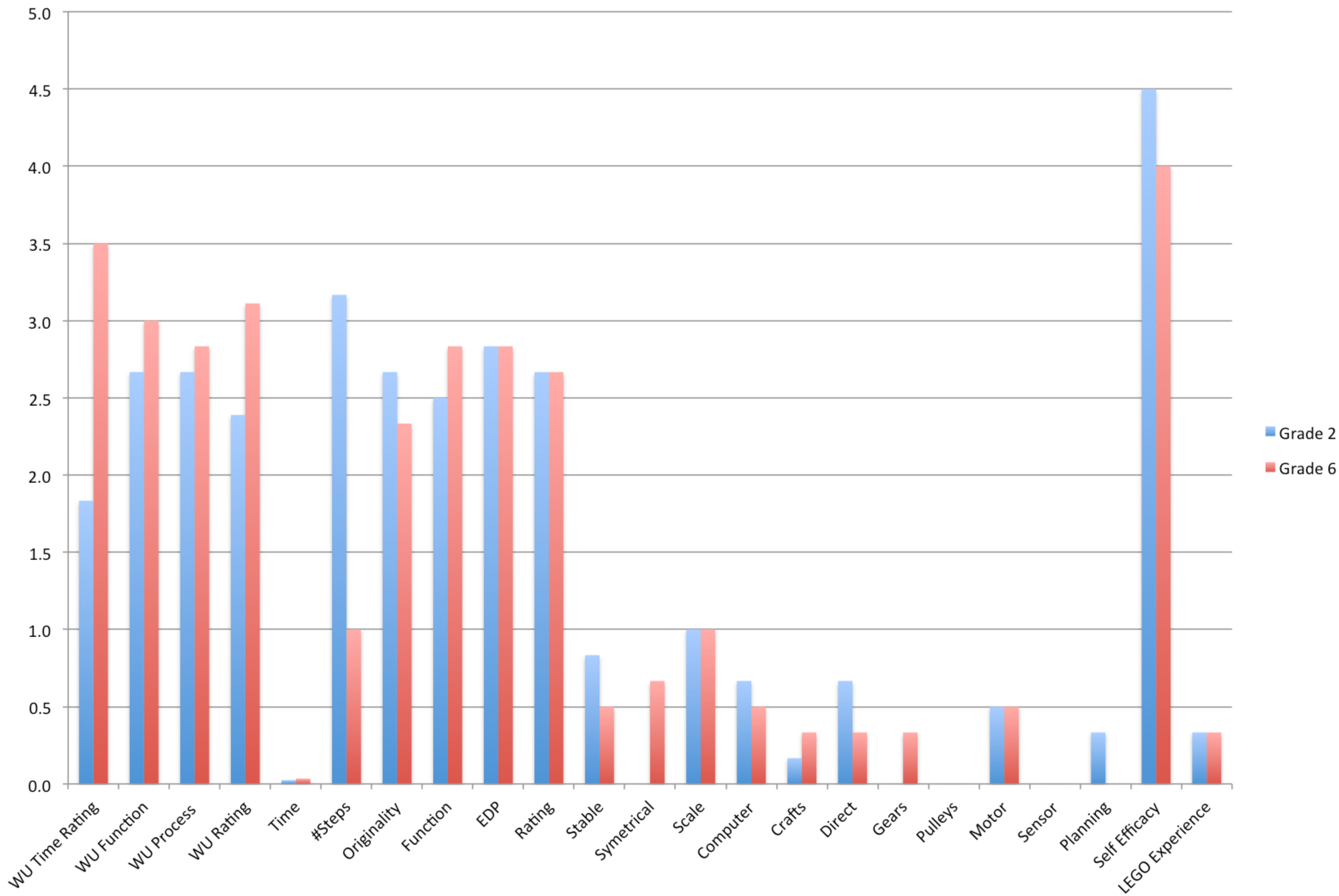
Data Collection Results

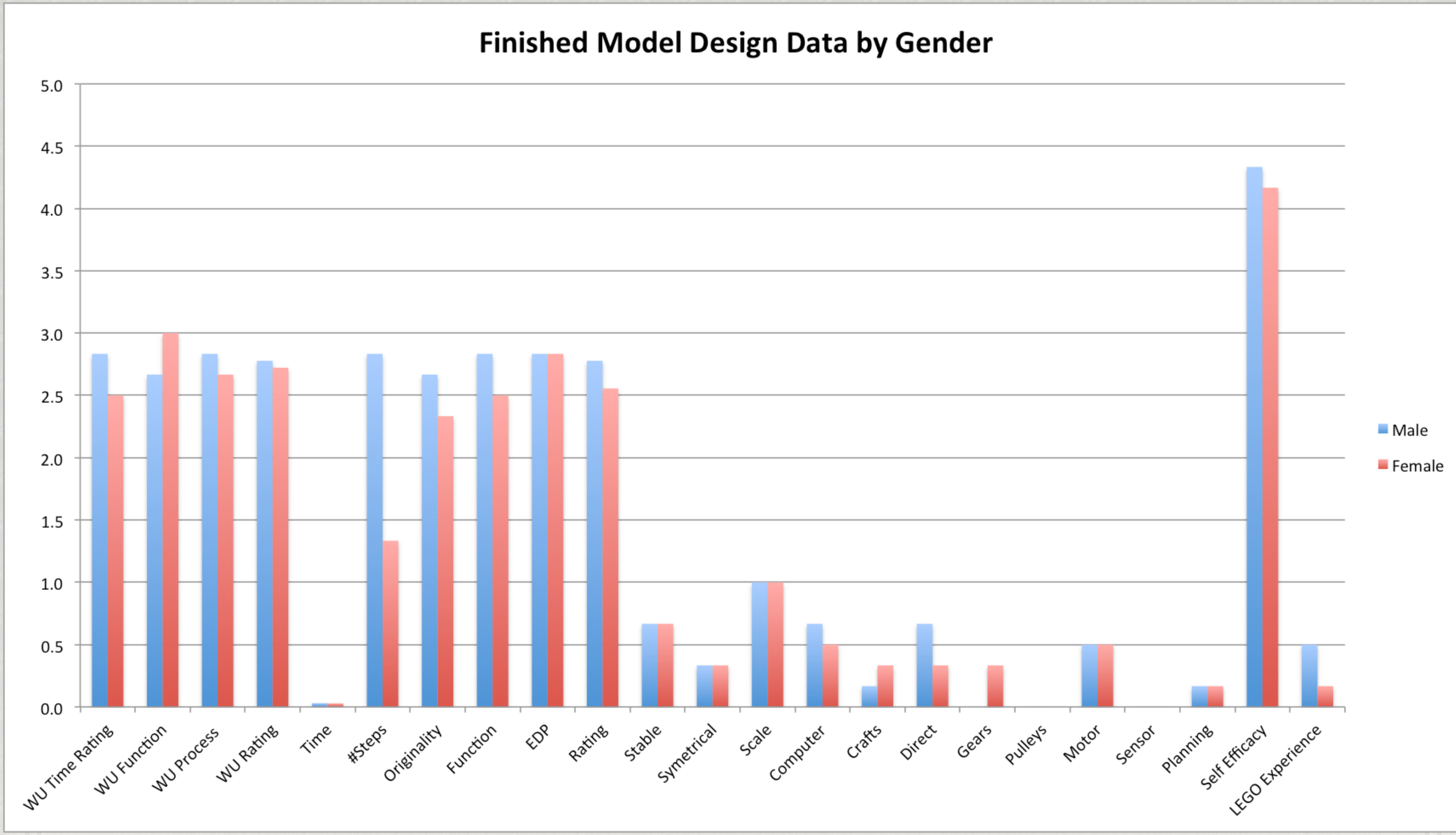
- *2 hours of warm up task and 8.5 hours of main task*
- *Multiple "track" issues with building and talking*
- *Transcription, time-stamping, segmenting, coding*
- *312 pages of segmented, coded transcripts*

Finished Model Design Data

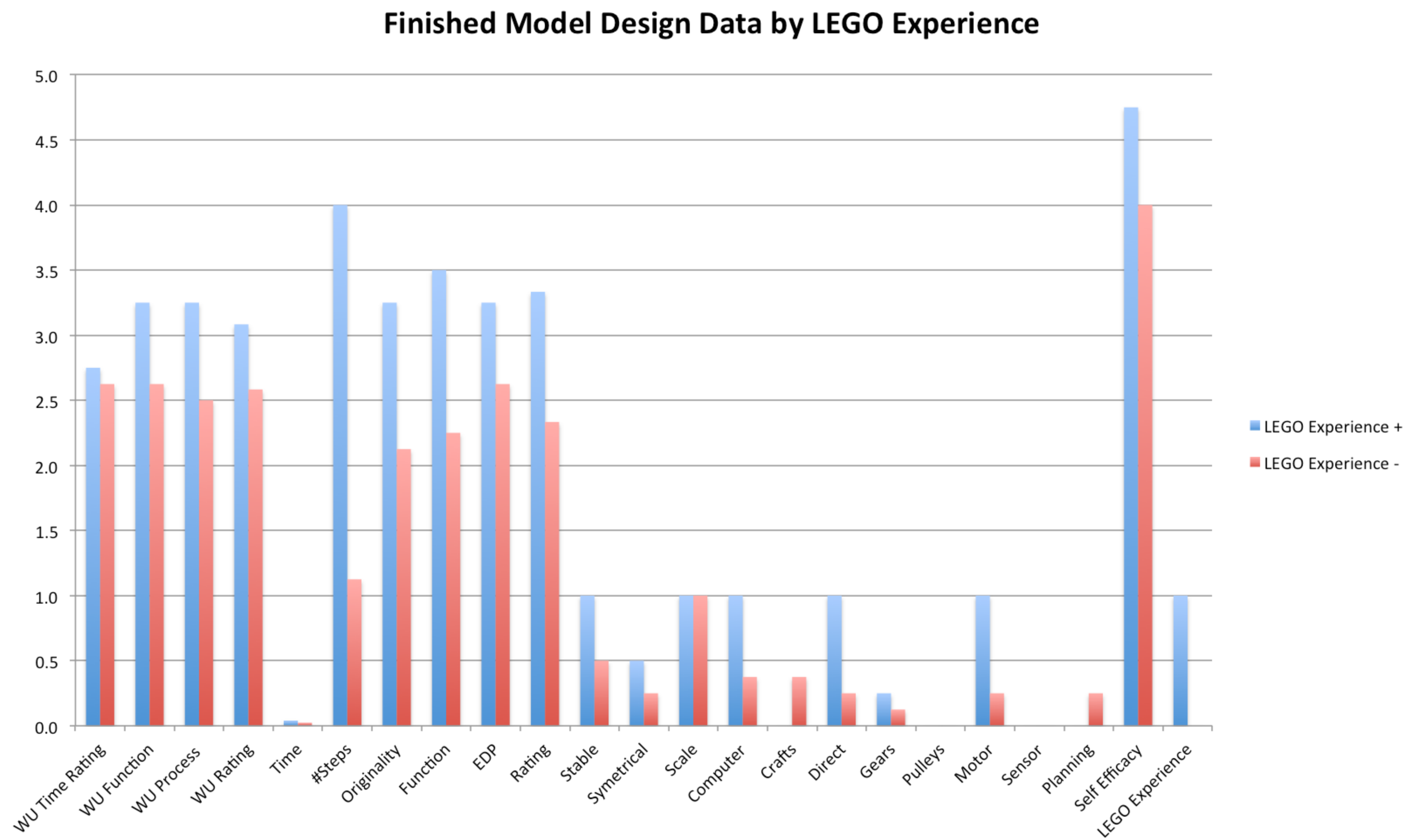
- *Warm Up Task - time, function, process (rubric)*
- *Ride quality - originality, function, process (rubric)*
- *Finished Model Design Data - #parts, time, use of different parts (motors, computer, crafts, sensors, gears, etc), stability, symmetry, scale*
- *Self Efficacy*

Finished Model Design Data by Grade Level



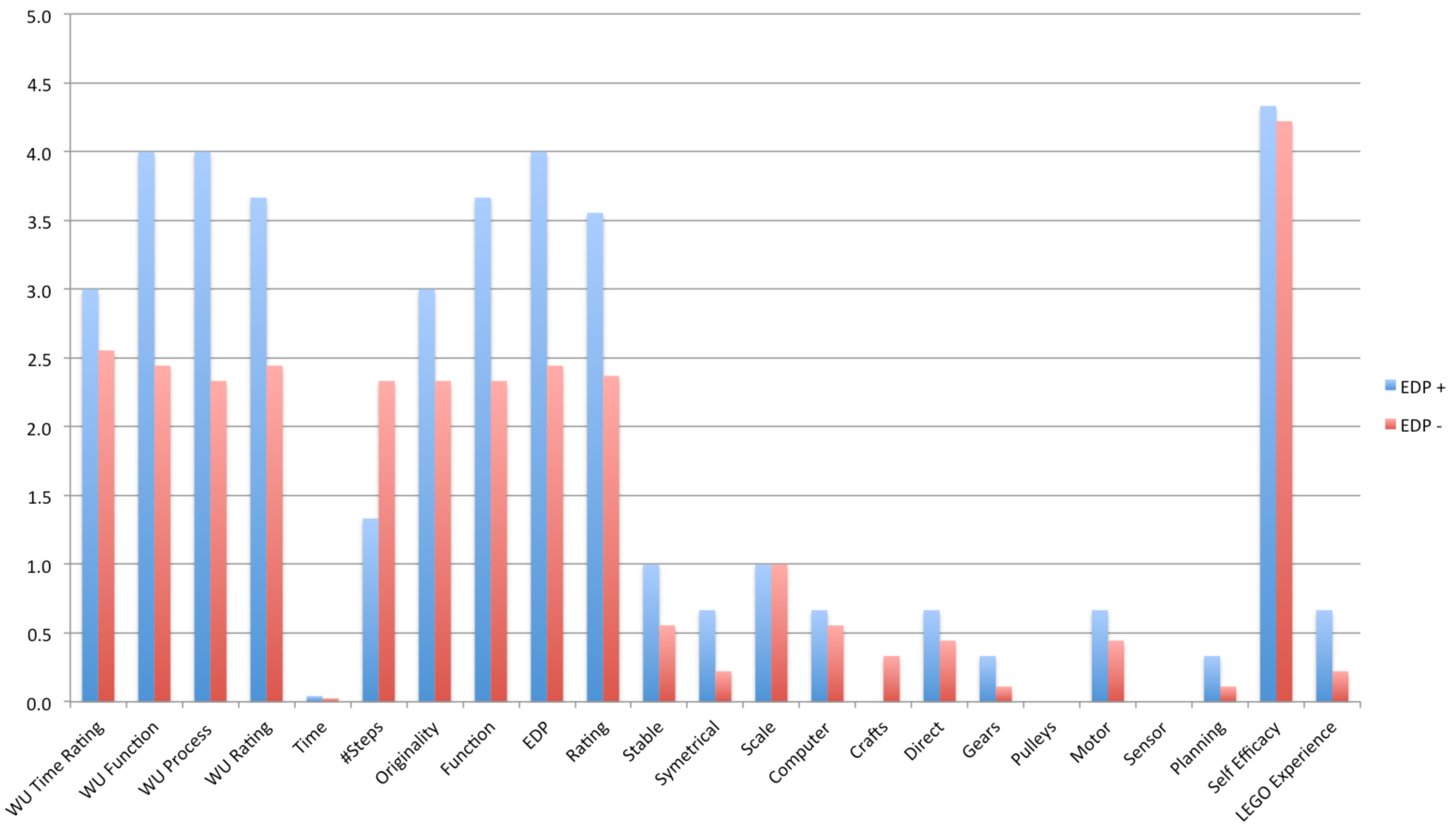


Finished Model Design Data by Gender
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
WU Time Rating
WU Function
WU Process
WU Rating
Time
#Steps
Originality
Function
EDP
Rating
Stable
Symetrical
Scale
Computer
Crafts
Direct
Gears
Pulleys
Motor
Sensor
Planning
Self Efficacy
LEGO Experience
Male
Female



Finished Model Design Data by LEGO Experience
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
WU Time Rating
WU Function
WU Process
WU Rating
Time
#Steps
Originality
Function
EDP
Rating
Stable
Symetrical
Scale
Computer
Crafts
Direct
Gears
Pulleys
Motor
Sensor
Planning
Self Efficacy
LEGO Experience
LEGO Experience +
LEGO Experience -

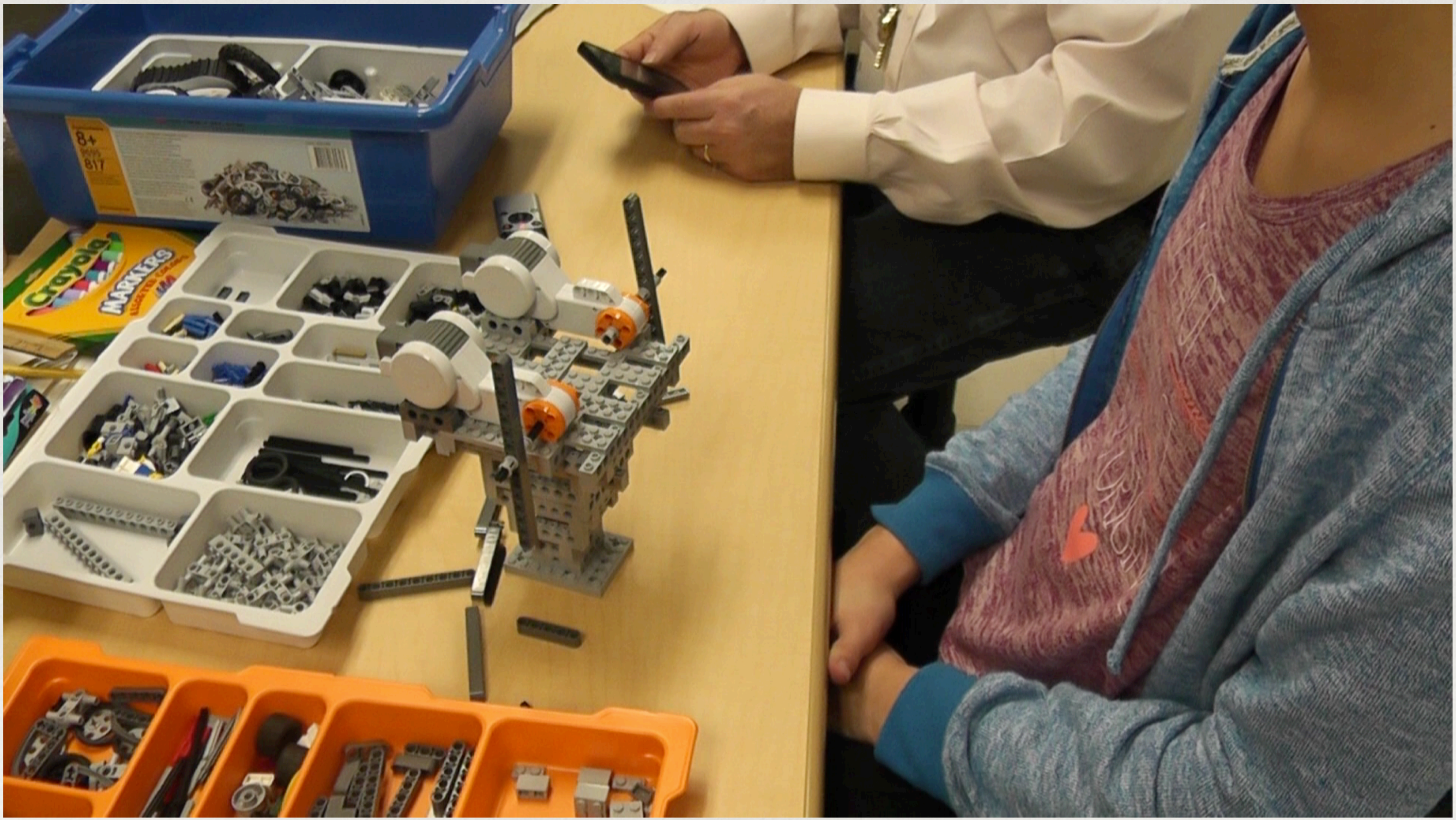
Finished Model Design Data by EDP+/-



Finished Model Analysis Summary

- *No major differences by gender or grade level!*
- *Differences noted **related to** LEGO Experience and EDP process*
- *But what exactly are the underlying factors?*
- *Would EDP timelines shed any light? Would they differ by gender or grade level or other factors?*

Sample Video Clip



Segmented Sample

[00:32:41] {moving}

[00:32:49] {no_activity}

Researcher: Yeah. There's always a challenge.

[00:32:51[{searching} Girl 05: Hmm. Trying to think about this. If I have this, that, that'll be upright. Yeah, that seems like it'll work. If I put one of these on each, I hope this will work. Put this on that, and that will run with ...

[00:32:53] {connecting}

[00:33:22] Girl 05: How am I going to connect that? It'll be like ...

[00:33:26] {moving}

[00:33:28] {connecting} Girl 05: Yeah, okay.

Researcher: Great idea.

[00:33:33] {measuring} Girl 05: Okay, where did my middle ...

[00:33:37] Girl 05: Yeah. Then it'll ...

[00:33:38] {connecting}

[00:33:40] {moving}

[00:33:42] Girl 05: Weird.

[00:33:53] {no_activity}

Coded and Segmented Sample

Girl 5 Segmented Coded Example

[00:32:41] [EVALUATE] {moving}

[00:32:49] [PLAN] {no_activity}

Researcher: Yeah. There's always a challenge.

[00:32:51] [PLAN] {searching} Girl 05: Hmm. Trying to think about this.

[00:32:57] [RESEARCH] Girl 5: If I have this, that, that'll be upright. Yeah, that seems like it'll work. If I put one of these on each, I hope this will work. Put this on that, and that will run with ...

[00:32:53] {connecting}

[00:33:22] Girl 05: How am I going to connect that? It'll be like ...

[00:33:26] {moving}

[00:33:28] [BUILD] {connecting} Girl 05: Yeah, okay.

Researcher: Great idea.

[00:33:33] {measuring} Girl 05: Okay, where did my middle ...

[00:33:37] Girl 05: Yeah. Then it'll ...

[00:33:38] {connecting}

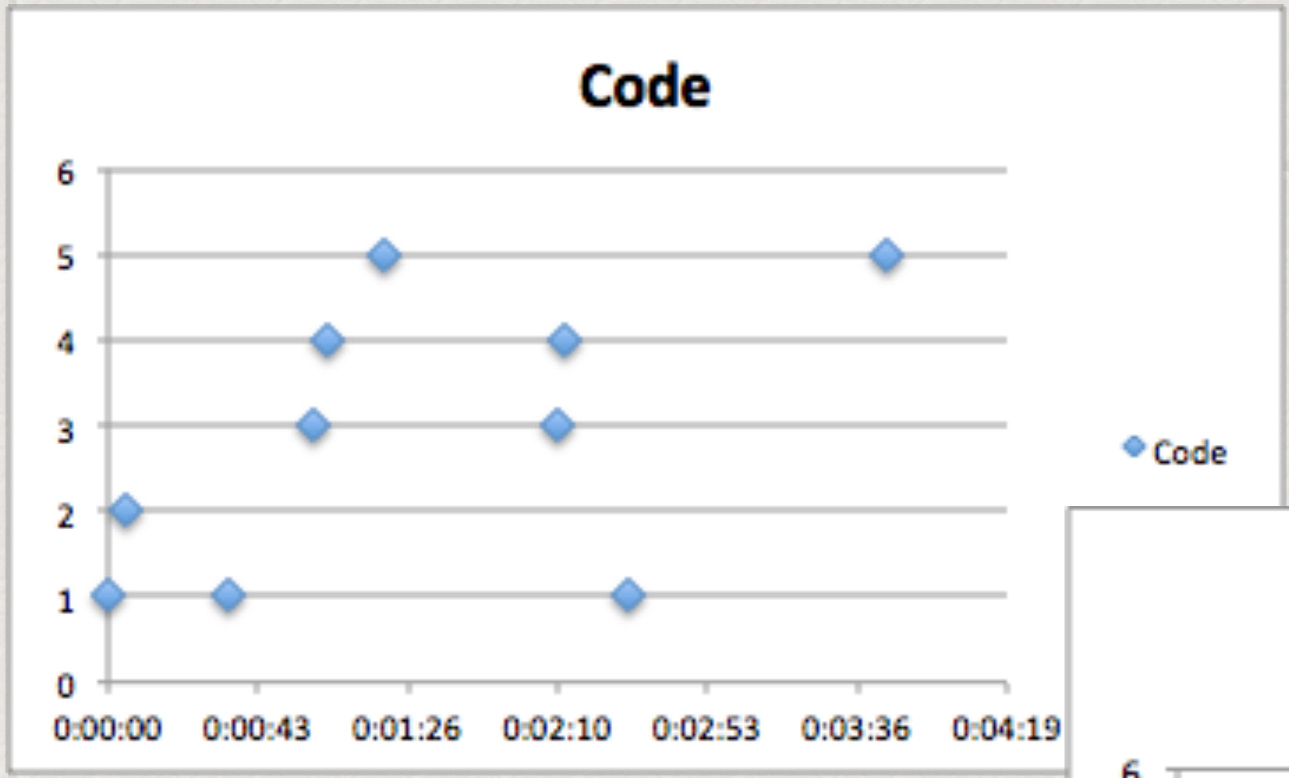
[00:33:40] [EVALUATE] {moving}

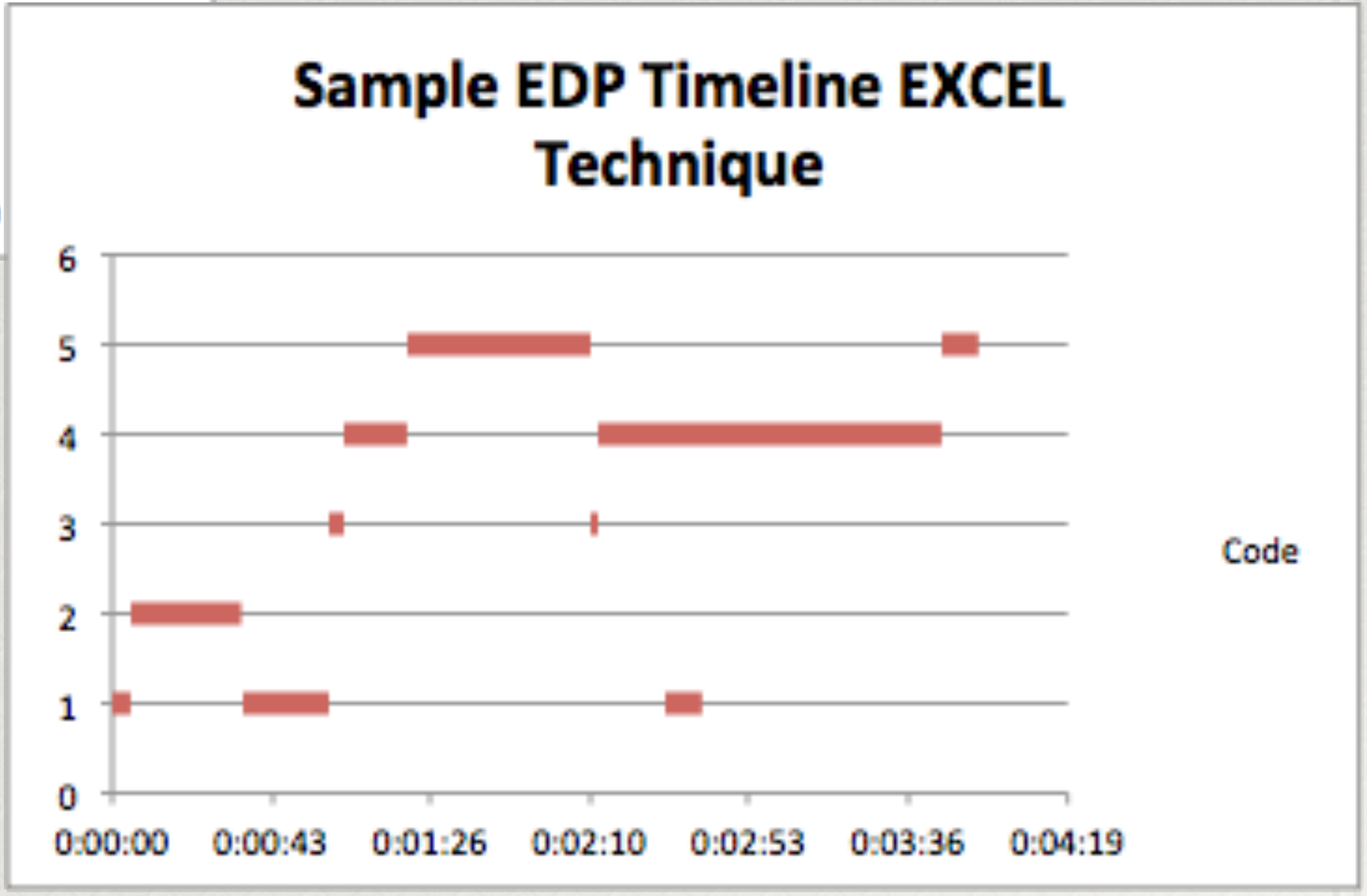
[00:33:42] Girl 05: Weird.

EXCEL Solution

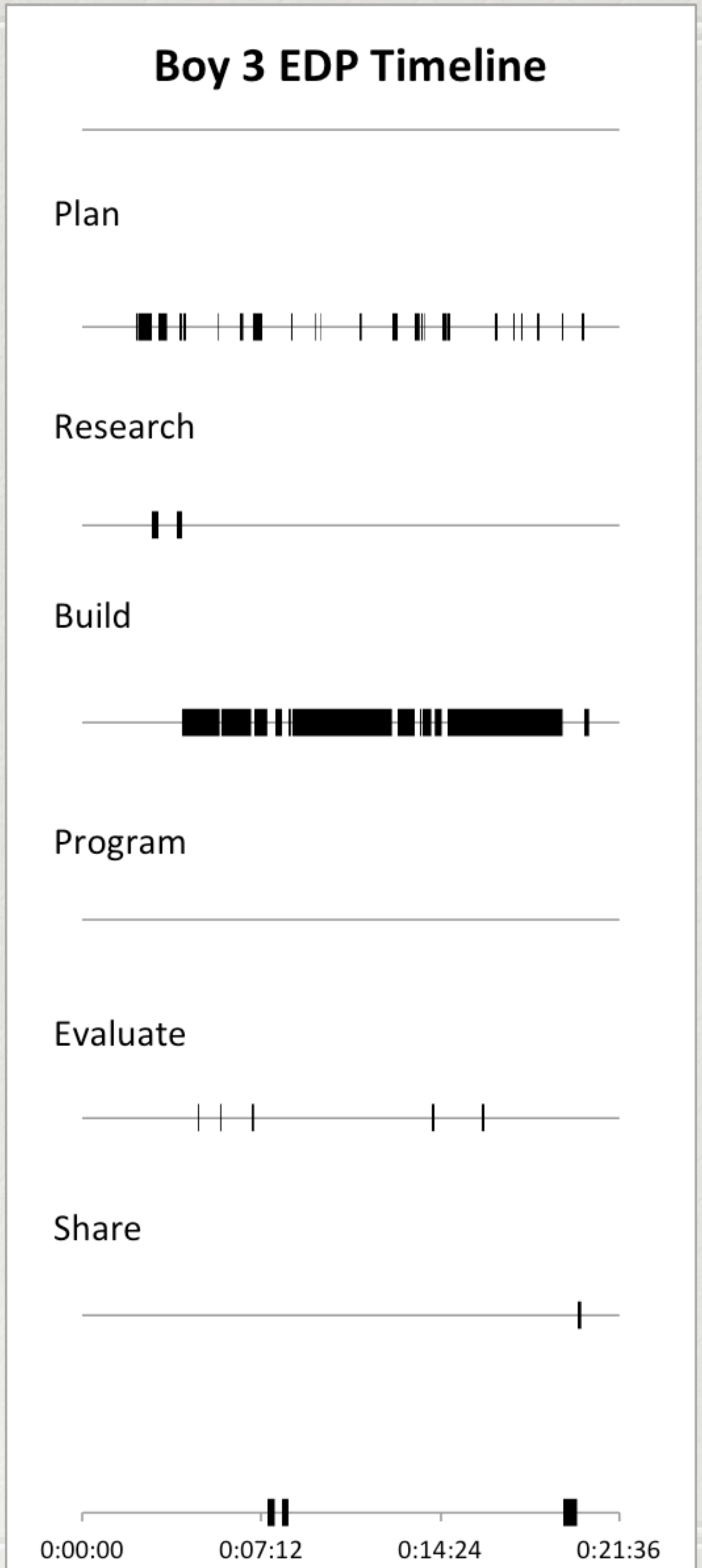
A	B	C	D	E
Start	Duration	Code	End	
0:00:00	0:00:05	1	0:00:05	
0:00:05	0:00:30	2	0:00:35	
0:00:35	0:00:24	1	0:00:59	
0:00:59	0:00:04	3	0:01:03	
0:01:03	0:00:17	4	0:01:20	
0:01:20	0:00:50	5	0:02:10	
0:02:10	0:00:02	3	0:02:12	
0:02:12	0:01:33	4	0:03:45	Overlap
0:02:30	0:00:10	1	0:02:40	Overlap
0:03:45	0:00:10	5	0:03:55	
0:03:55				

EXCEL Solution 2

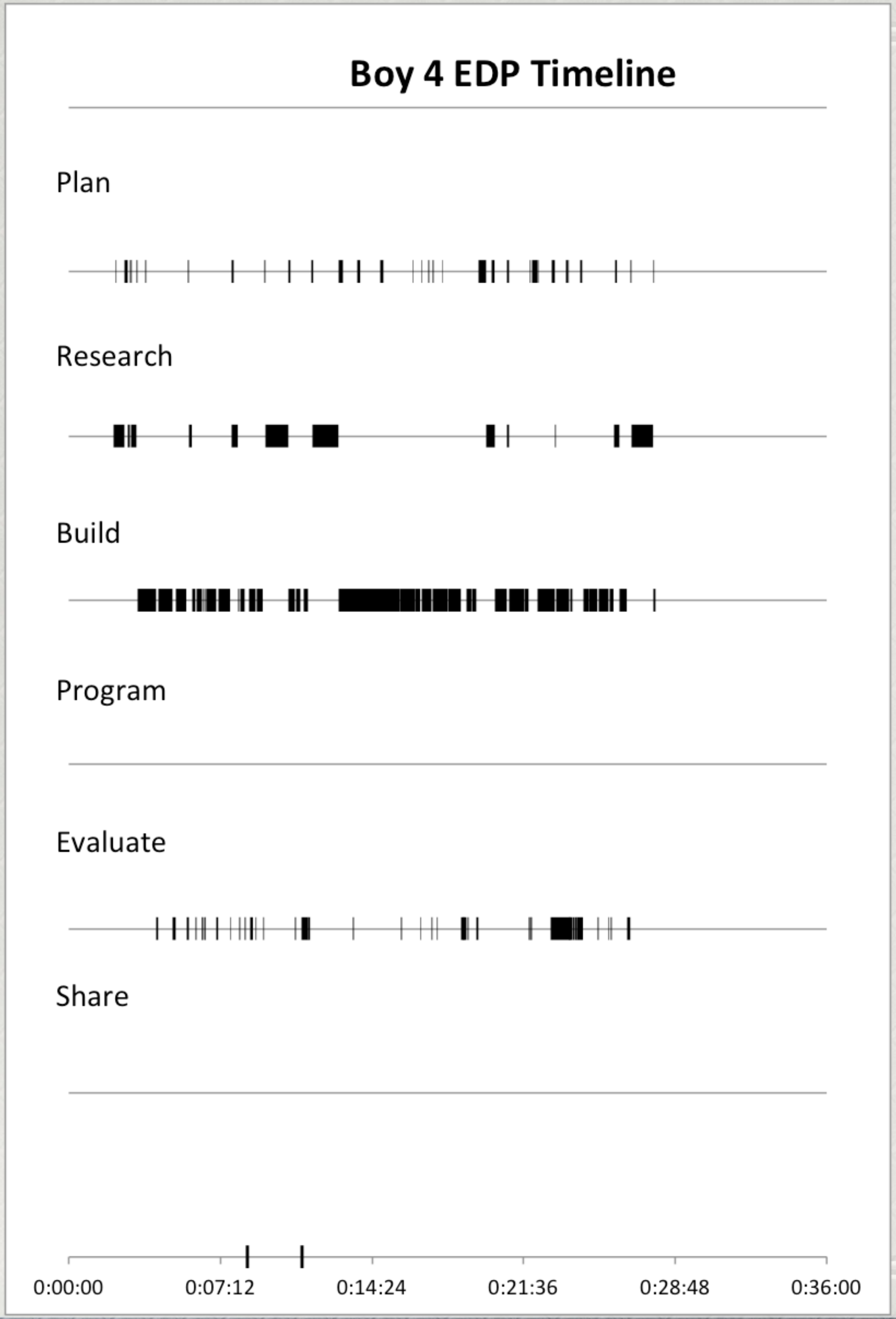




Low complexity, low tools

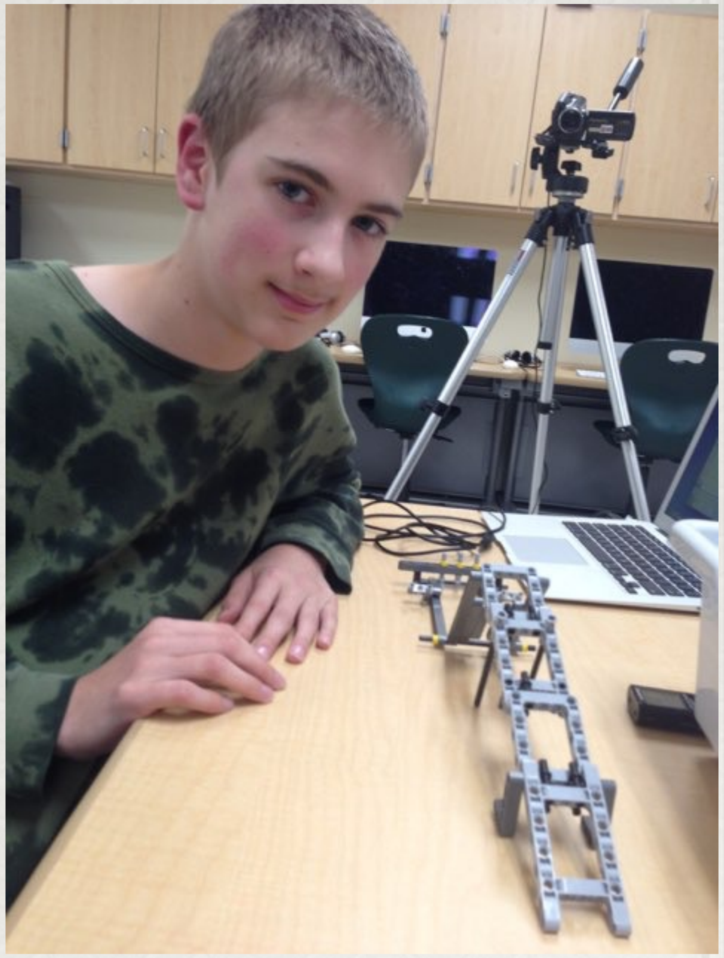


Gender Subject	Boy 3
Grade Level	6
Model Rating	2.0
Prelim EDP Rating	2
LEGO Experience	0
Motor	0
SK	Low
Math/Science	Low
Design Principles	Low
EDP Process	Low
CR	Medium
Plan-Ahead	Low
CF	Medium

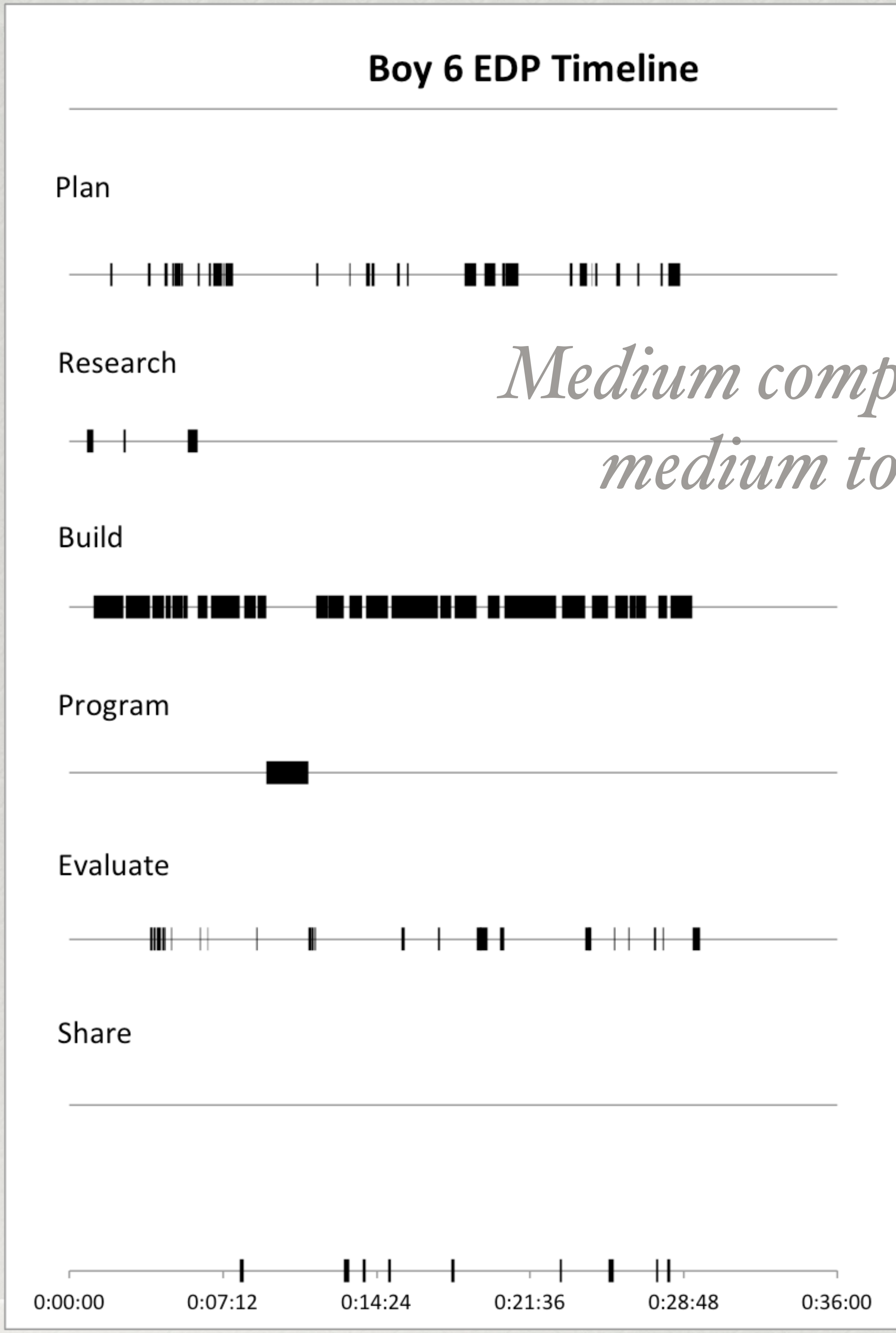


Gender Subject	Boy 4
Grade Level	6
Model Rating	2.7
Prelim EDP Rating	3
LEGO Experience	0
Motor	0
SK	High
Math/Science	Medium
Design Principles	High
EDP Process	Medium
CR	High
Plan-Ahead	Low
CF	Medium

Low complexity, medium tools*



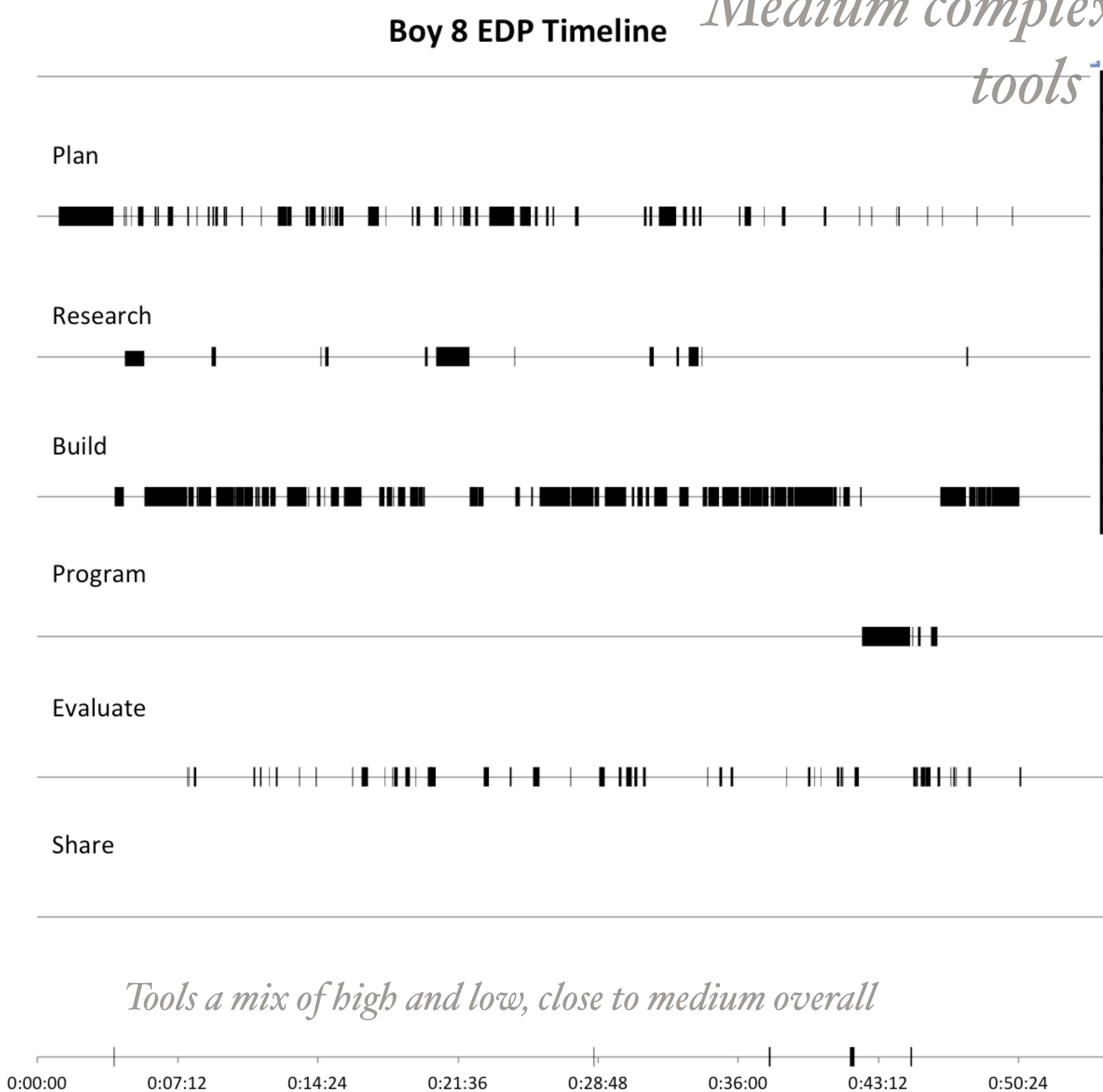
** close to medium complexity*



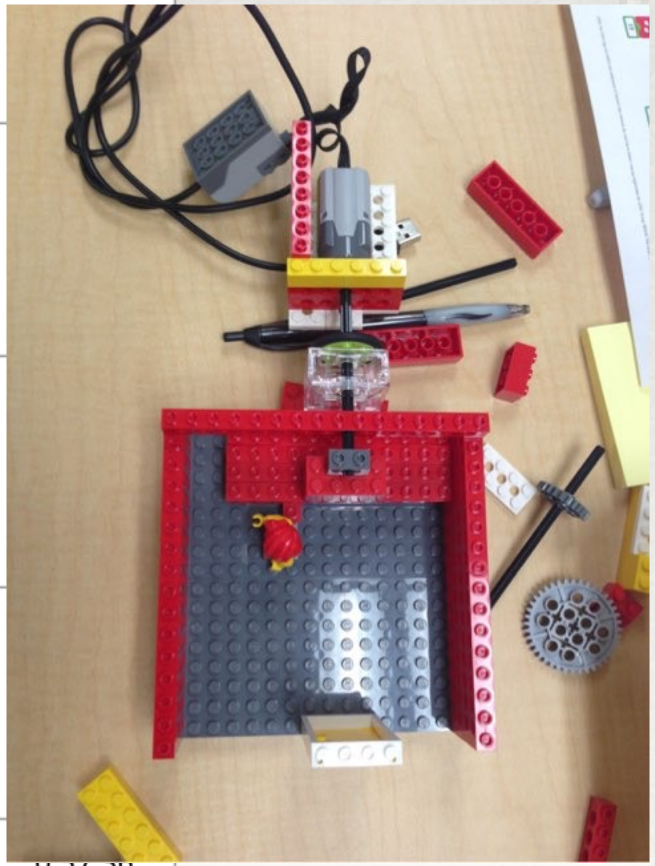
Medium complexity, medium tools

Gender Subject	Boy 6
Grade Level	2
Model Rating	3.0
Prelim EDP Rating	3
LEGO Experience	1
Motor	1
SK	Medium
Math/Science	Low
Design Principles	Low
EDP Process	High
CR	High
Plan-Ahead	Low
CF	High

Medium complexity, Low* tools

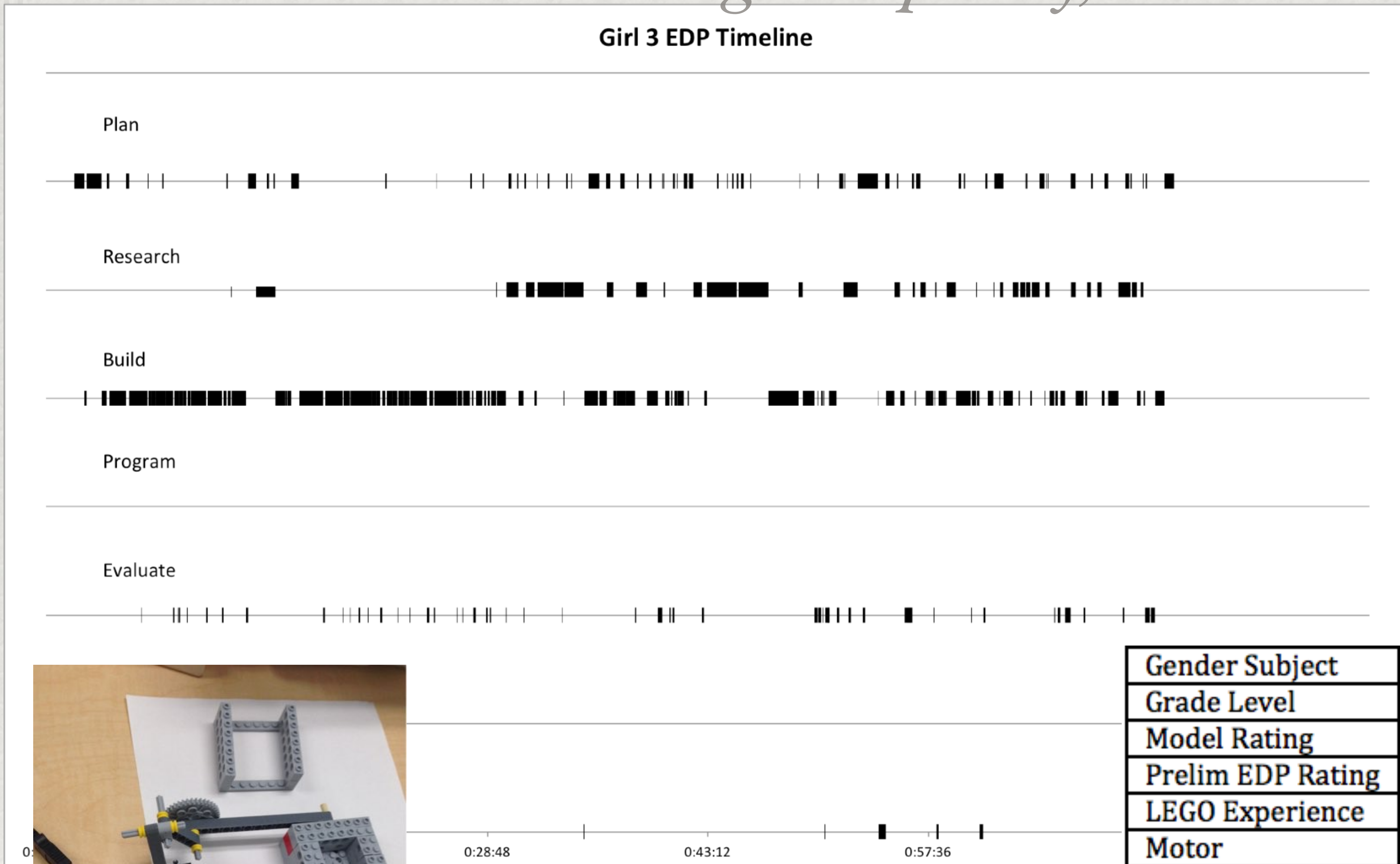


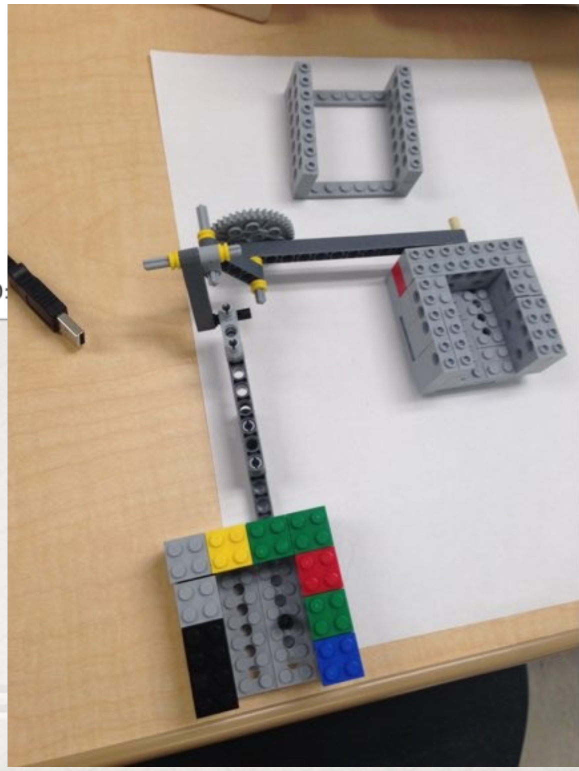
Gender Subject	Boy 8
Grade Level	2
Model Rating	2.3
Prelim EDP Rating	3
LEGO Experience	0
Motor	1
SK	Low
Math/Science	High
Design Principles	Low
EDP Process	High
CR	Low
Plan-Ahead	High
CF	Low



Tools a mix of high and low, close to medium overall

High complexity, low tools

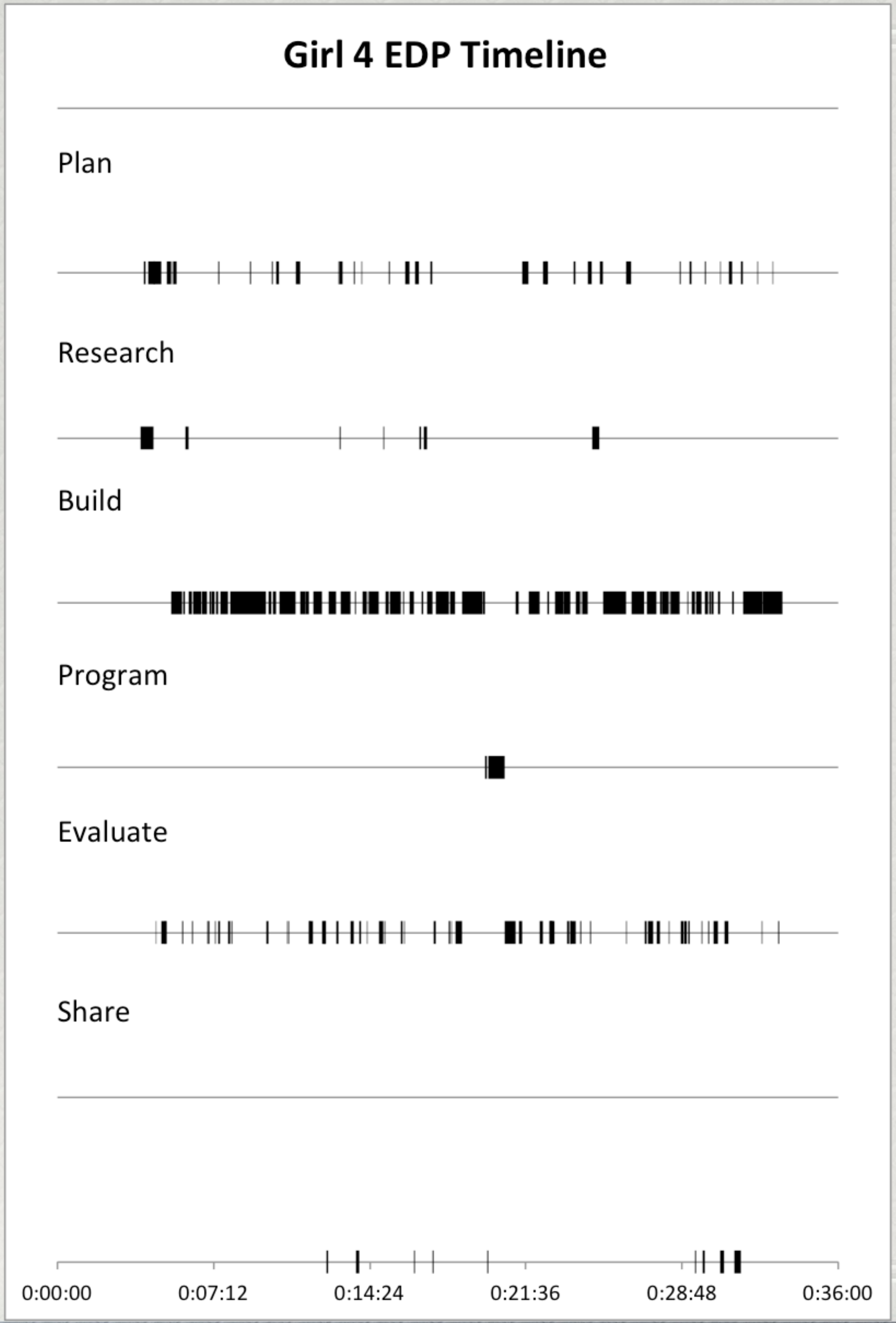




Never finished

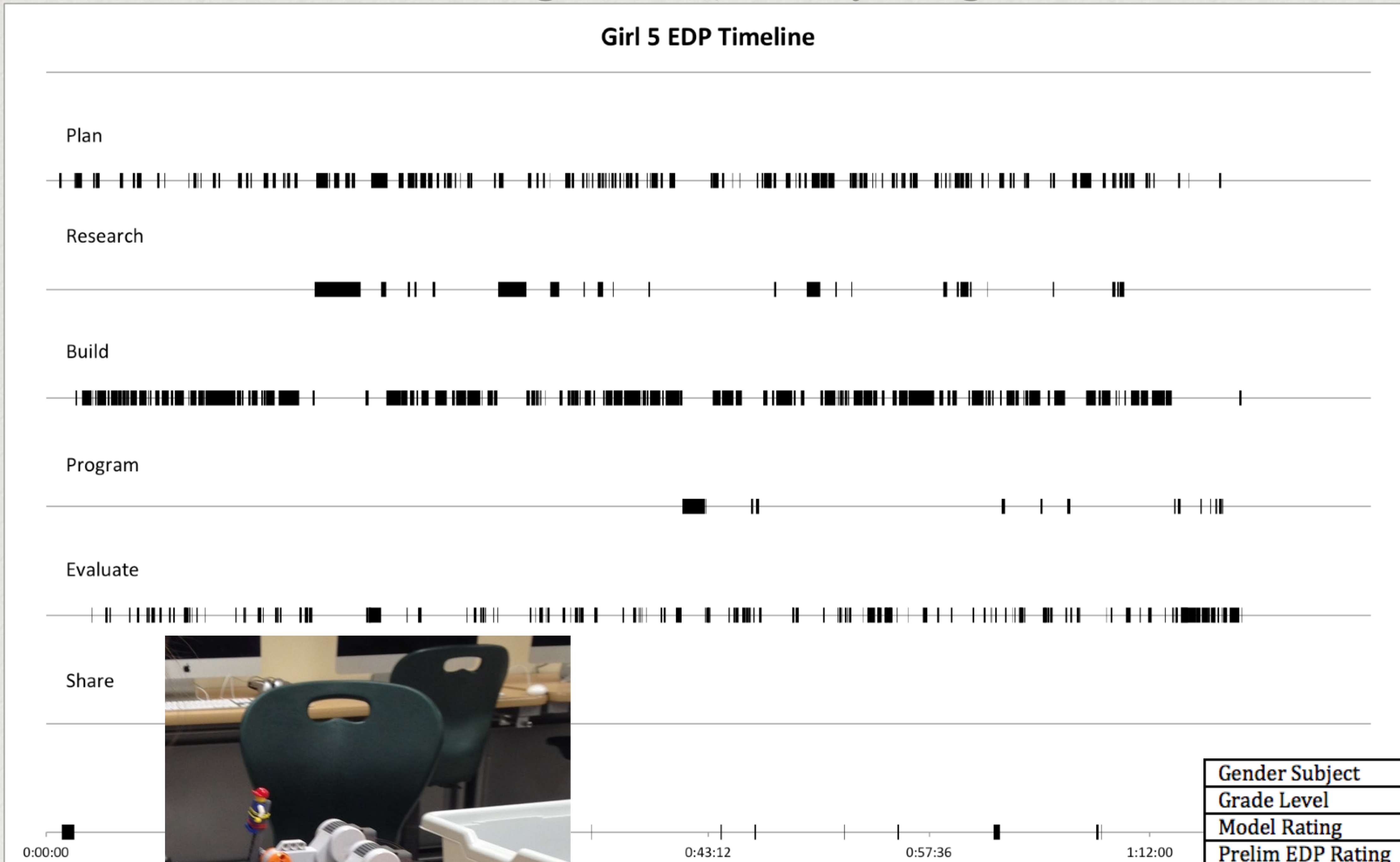
Gender Subject	Girl 3
Grade Level	6
Model Rating	1.3
Prelim EDP Rating	2
LEGO Experience	0
Motor	1 (Intended)
SK	Low
Math/Science	Low
Design Principles	Low
EDP Process	Medium
CR	Low
Plan-Ahead	Low
CF	Low

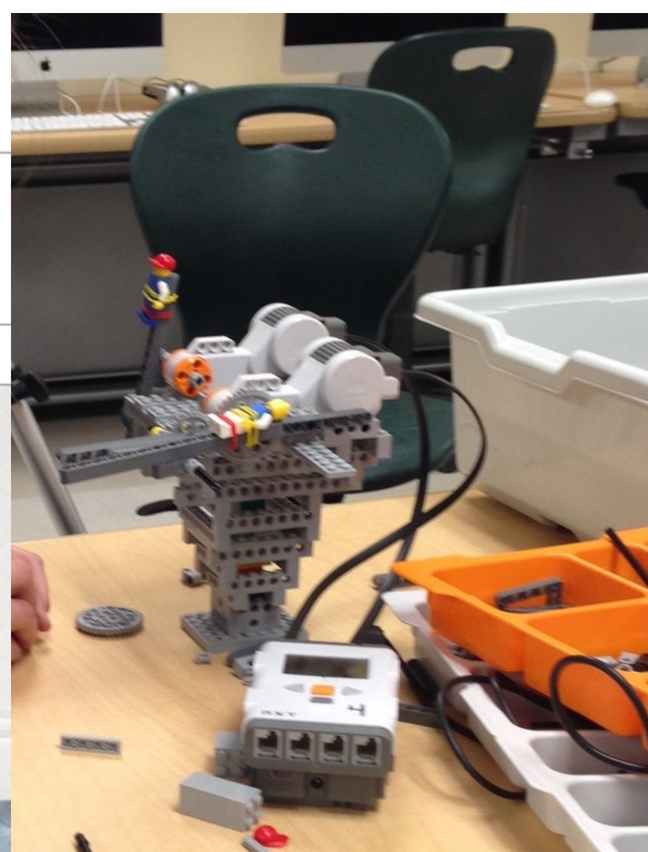
Medium complexity, medium tools



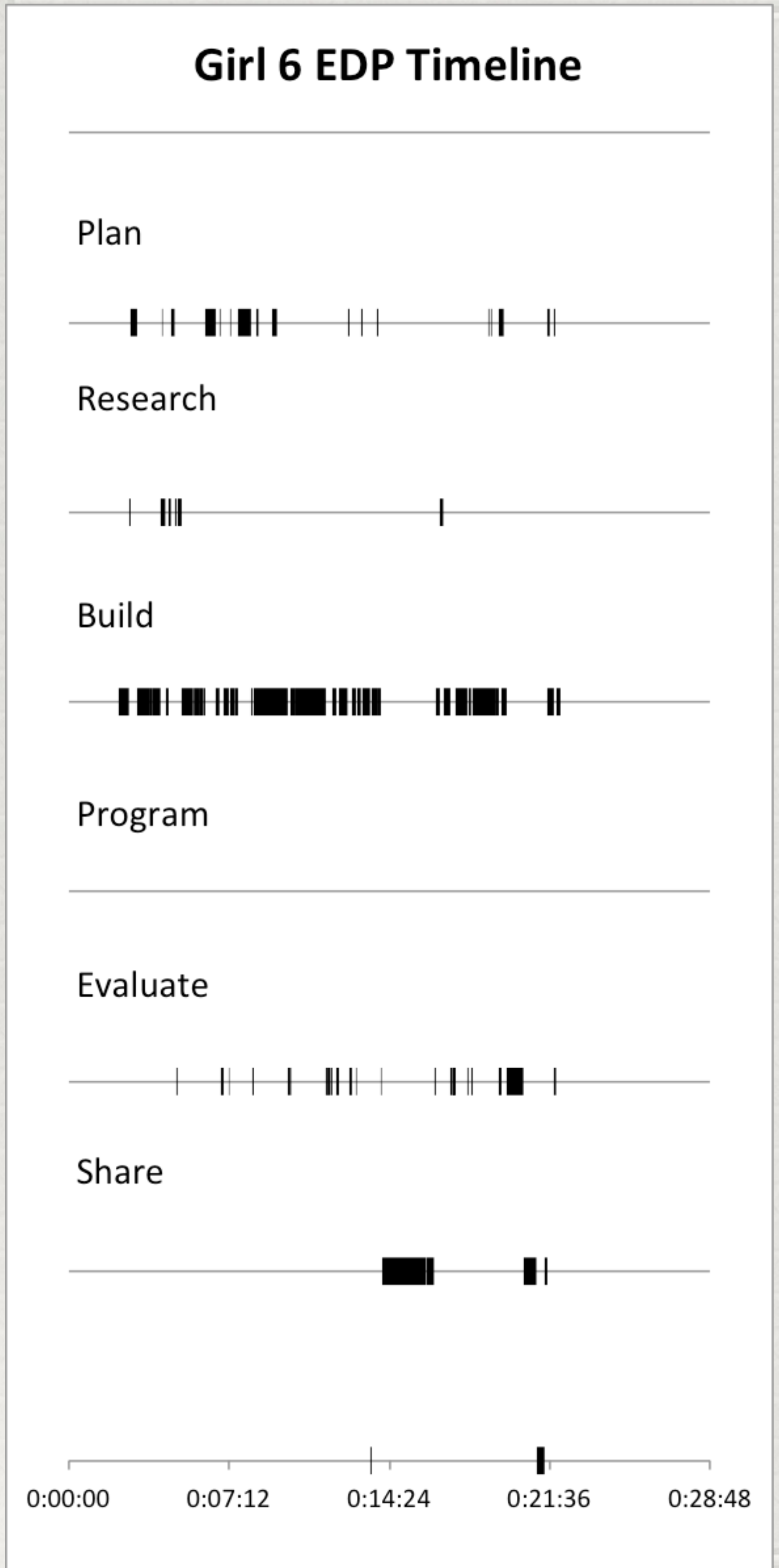
Gender Subject	Girl 4
Grade Level	6
Model Rating	2.7
Prelim EDP Rating	2
LEGO Experience	0
Motor	1
SK	Low
Math/Science	Low
Design Principles	Medium
EDP Process	Medium
CR	High
Plan-Ahead	Medium
CF	Medium

High complexity, high tools

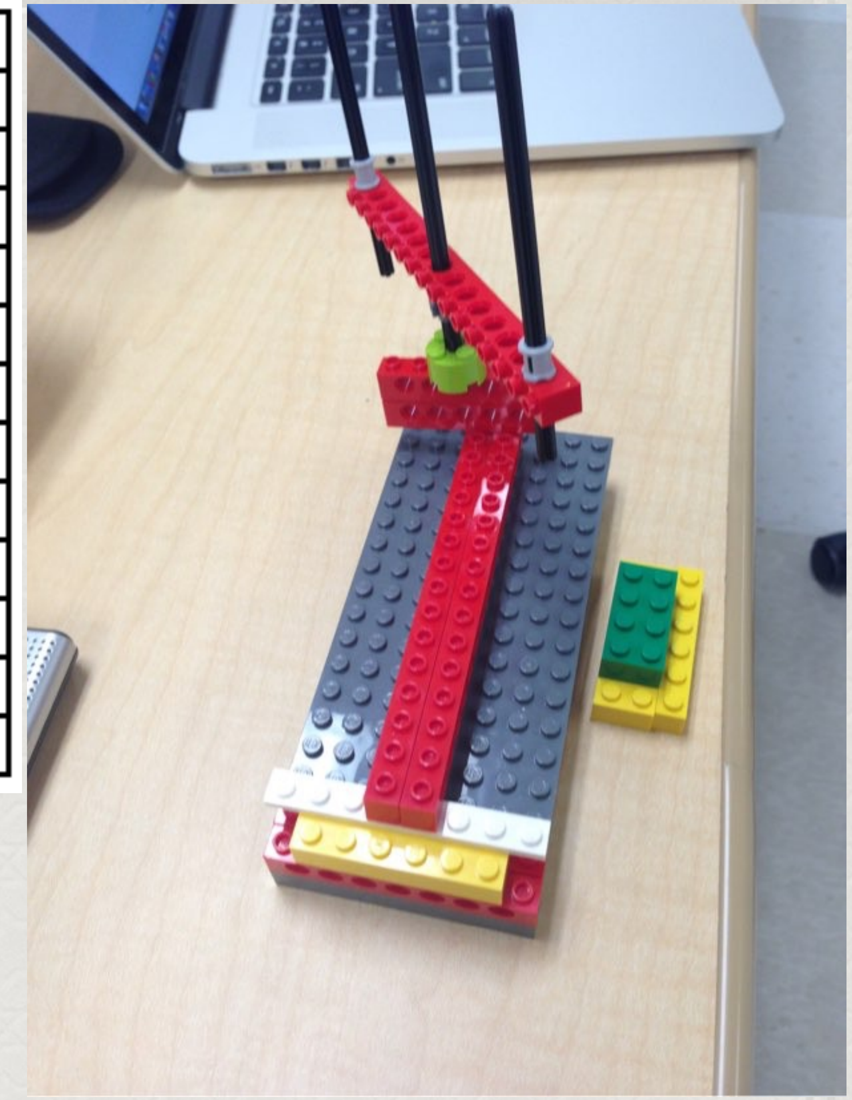




Gender Subject	Girl 5
Grade Level	6
Model Rating	3.7
Prelim EDP Rating	4
LEGO Experience	1
Motor	1
SK	High
Math/Science	High
Design Principles	High
EDP Process	High
CR	High
Plan-Ahead	High
CF	High



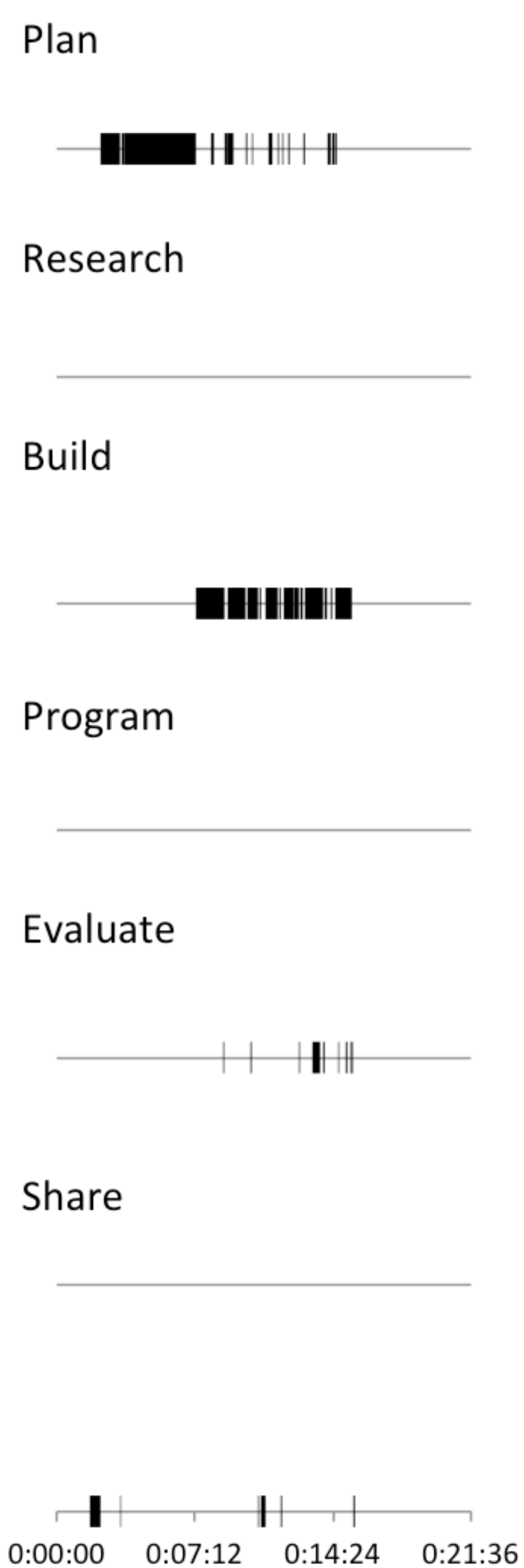
Gender Subject	Girl 6
Grade Level	2
Model Rating	2.0
Prelim EDP Rating	3
LEGO Experience	0
Motor	0
SK	Low
Math/Science	Low
Design Principles	Medium
EDP Process	Medium
CR	Low
Plan-Ahead	Low
CF	Medium



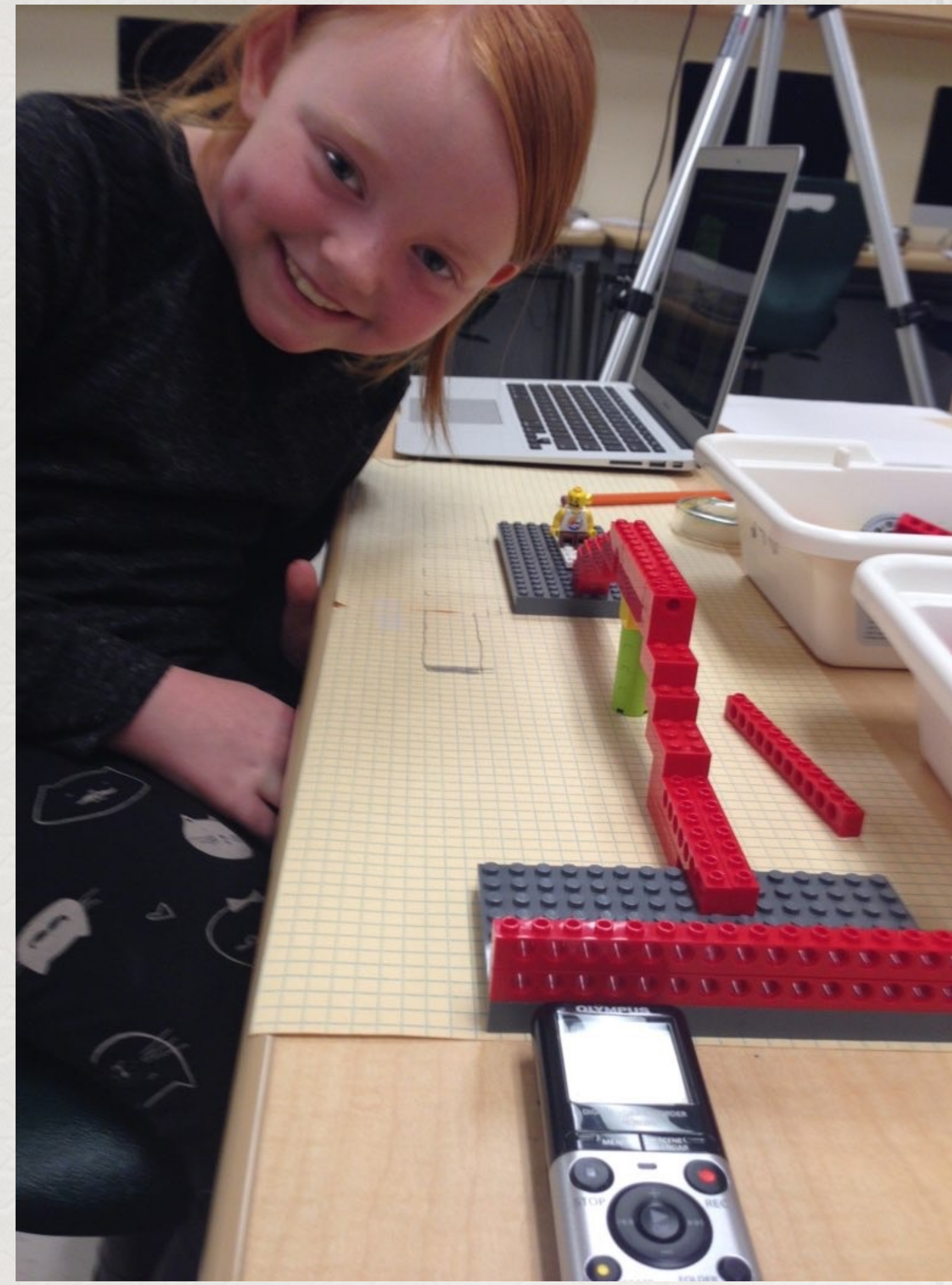
Low complexity, low tools

Low complexity, high tools

Girl 8 EDP Timeline



Gender Subject	Girl 8
Grade Level	2
Model Rating	3.3
Prelim EDP Rating	4
LEGO Experience	0
Motor	0
SK	High
Math/Science	High
Design Principles	High
EDP Process	High
CR	High
Plan-Ahead	High
CF	Medium



Subject	Structural Knowledge	Math/ Science	Design Principles	EDP Process	CR	Planning	CF	Overall Knowledge and Process Rating (Tools)	Build Complexity
Boy 06	Medium	Low	Low	High	High	Low	High	Medium	High
Boy 07	Medium	Low	Medium	Medium	Medium	Low	Low	Medium	Medium
Boy 08	Low	High	Low	High	Low	High	Low	Low*	Medium
Girl 06	Low	Low	Medium	Medium	Low	Low	Medium	Low	Low
Girl 08	High	High	High	High	High	High	Medium	High	Low
Girl 09	Low	Medium	Medium	Low	Medium	Low	Medium	Medium	Medium
Boy 03	Low	Low	Low	Low	Medium	Low	Medium	Low	Low
Boy 04	High	Medium	High	Medium	High	Low	Medium	Medium	Low
Boy 05	High	Medium	High	Medium	High	High	Medium	High	High
Girl 03	Low	Low	Low	Medium	Low	Low	Low	Low	High
Girl 04	Low	Low	Medium	Medium	High	Medium	Medium	Medium	Medium
Girl 05	High	High	High	High	High	High	High	High	High

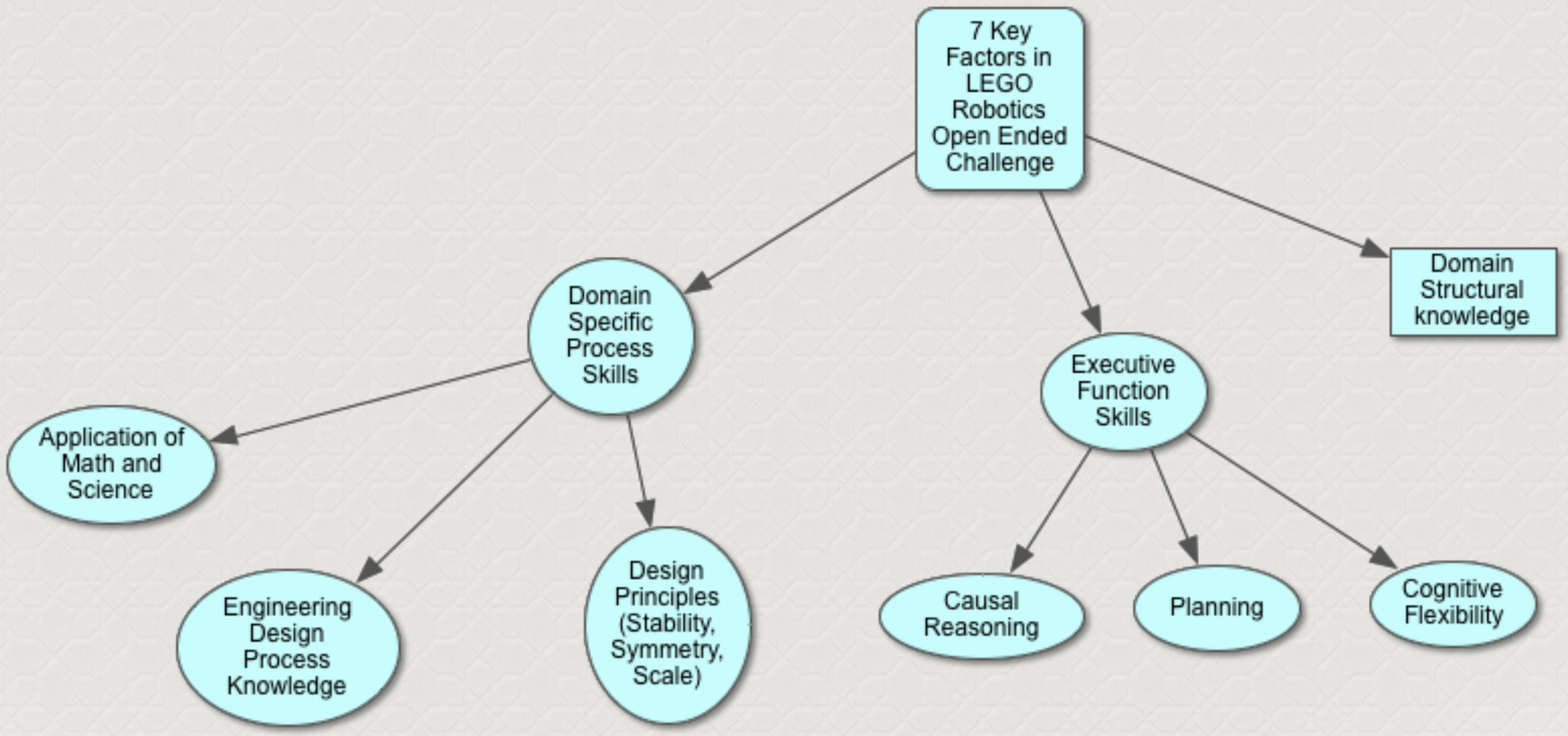
Tools \ Complexity	Low	Medium	High
Low	Boy 3, Girl 6	Boy 8	Girl 3
Medium	Boy 4	Girl 4, Boy 7, Girl 9, Boy 6	
High	Girl 8		Girl 5, Boy 5

Look at graphs especially outliers:

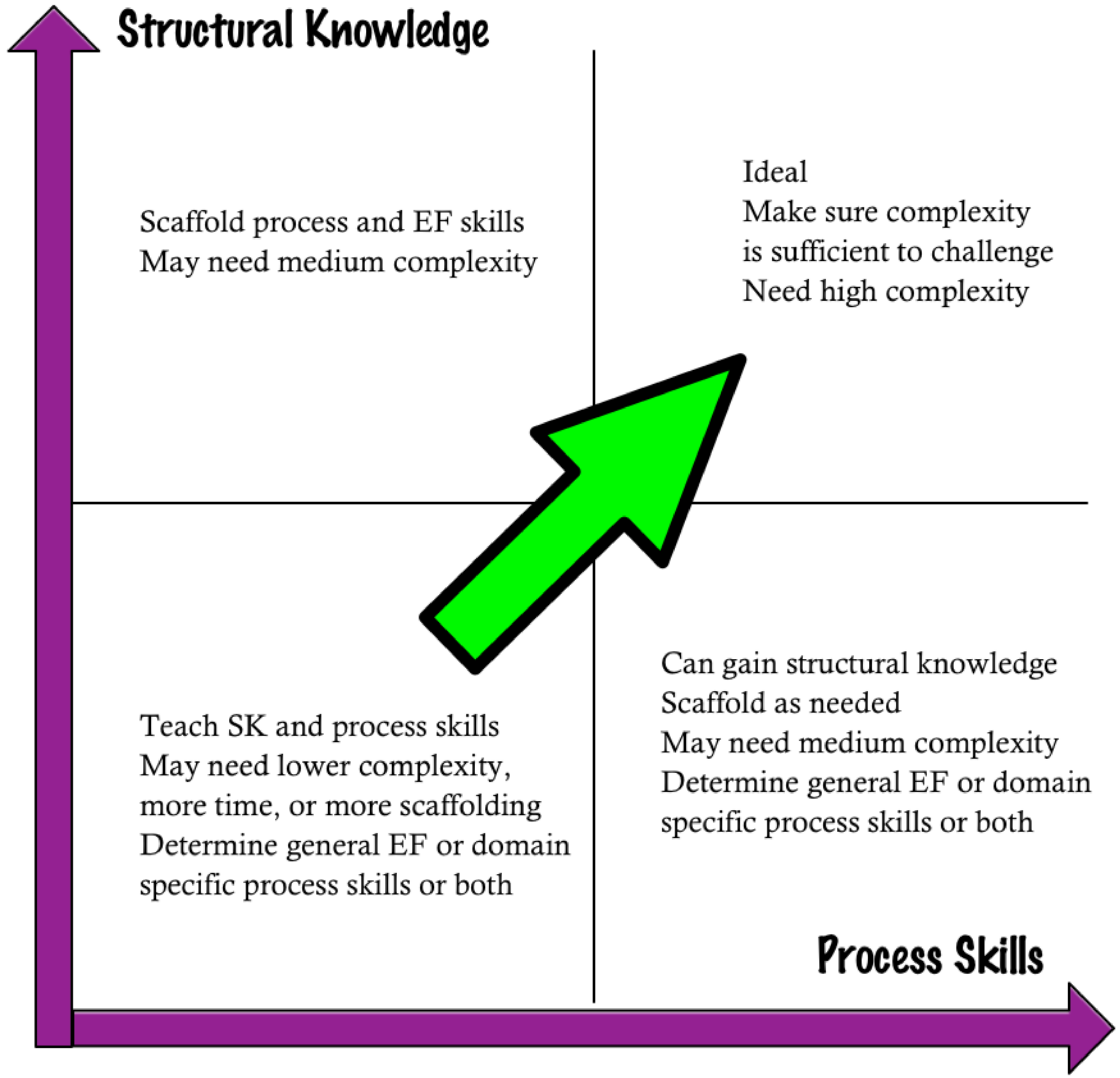
- *Girl 5, Boy 5 - dense, mix of phases throughout*
- *Boy 3, Girl 6 - build away!*
- *Girl 3 - DNF, ongoing research and planning, which never resolved issues, serial building did not work for her*
- *Girl 8 - "idealized" EDP - plan and build*

EDP Patterns

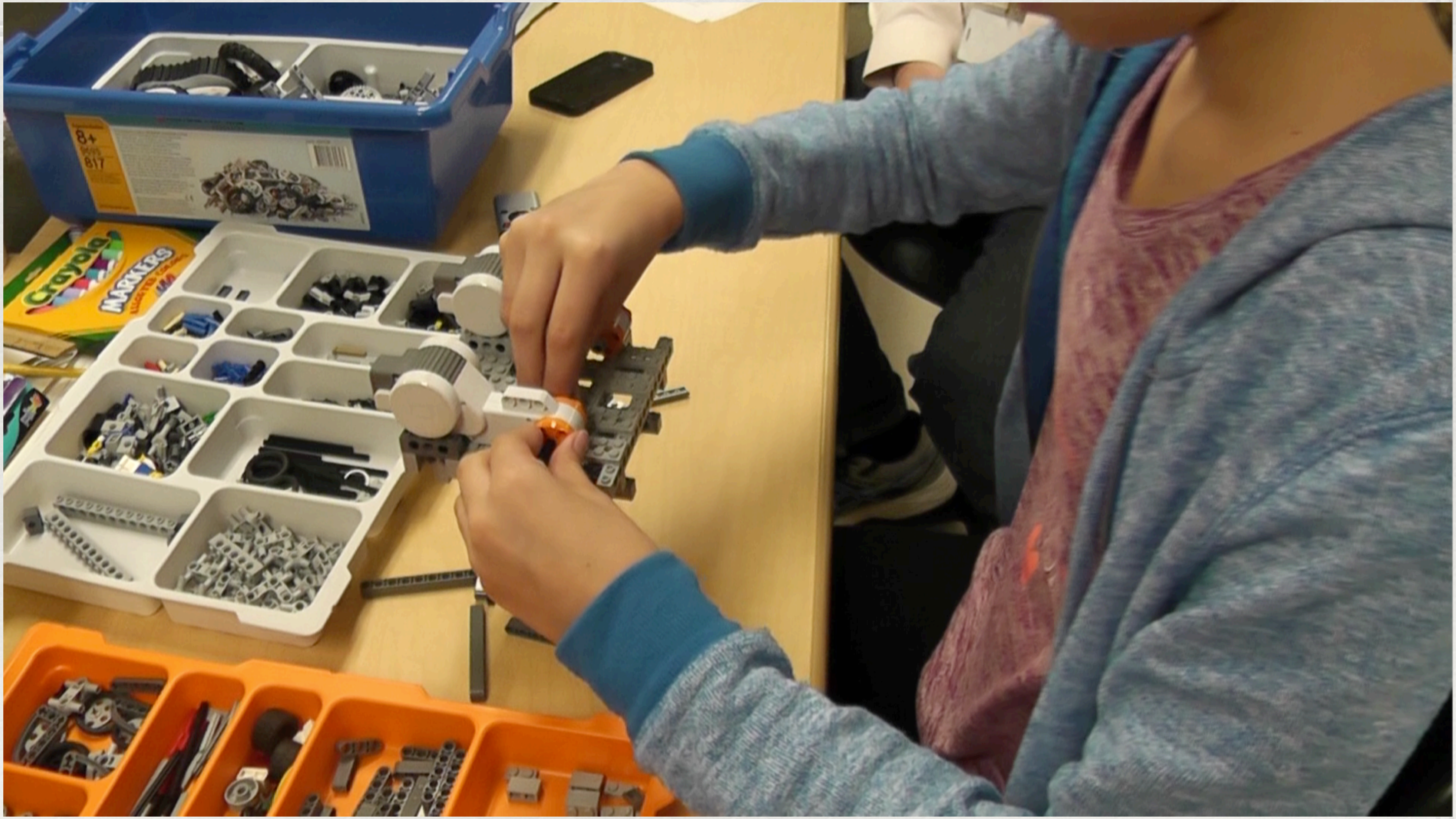
- *No clear patterns by single independent variable*
- *CR in particular may be the only direct, developmental variable in this context of age appropriate materials and instruction*
- *EDP patterns most dependent on build complexity and students tool set - 7 key factors*



7 Key Factors in LEGO Robotics Open Ended Challenge
Domain Specific Process Skills
Executive Function Skills
Domain Structural knowledge
Application of Math and Science
Engineering Design Process Knowledge
Design Principles (Stability, Symmetry, Scale)
Causal Reasoning
Planning
Cognitive Flexibility


Structural Knowledge
Scaffold process and EF skills
May need medium complexity
Ideal
Make sure complexity
is sufficient to challenge
Need high complexity
Teach SK and process skills
May need lower complexity,
more time, or more scaffolding
Determine general EF or domain
specific process skills or both
Can gain structural knowledge
Scaffold as needed
May need medium complexity
Determine general EF or domain
specific process skills or both
Process Skills

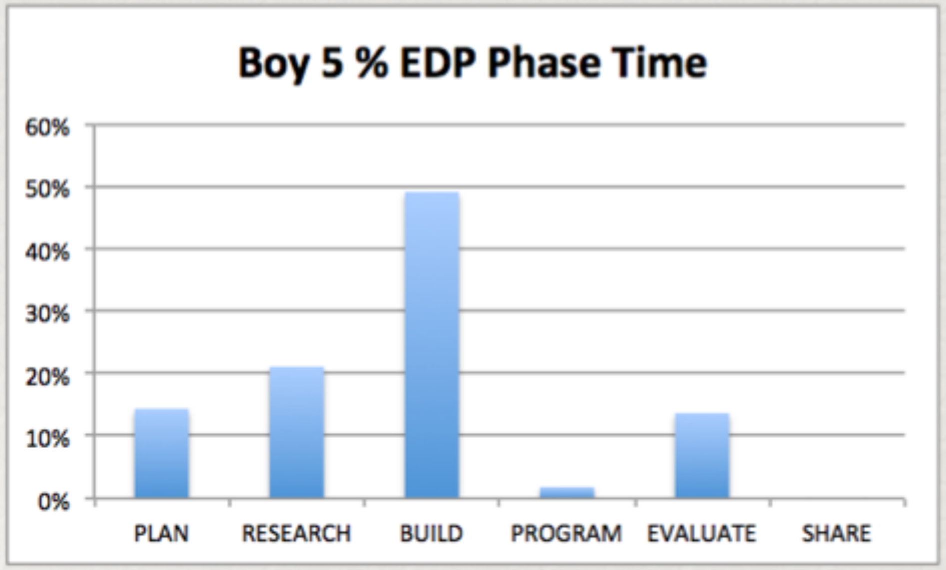
Girl 5 Learning Moment

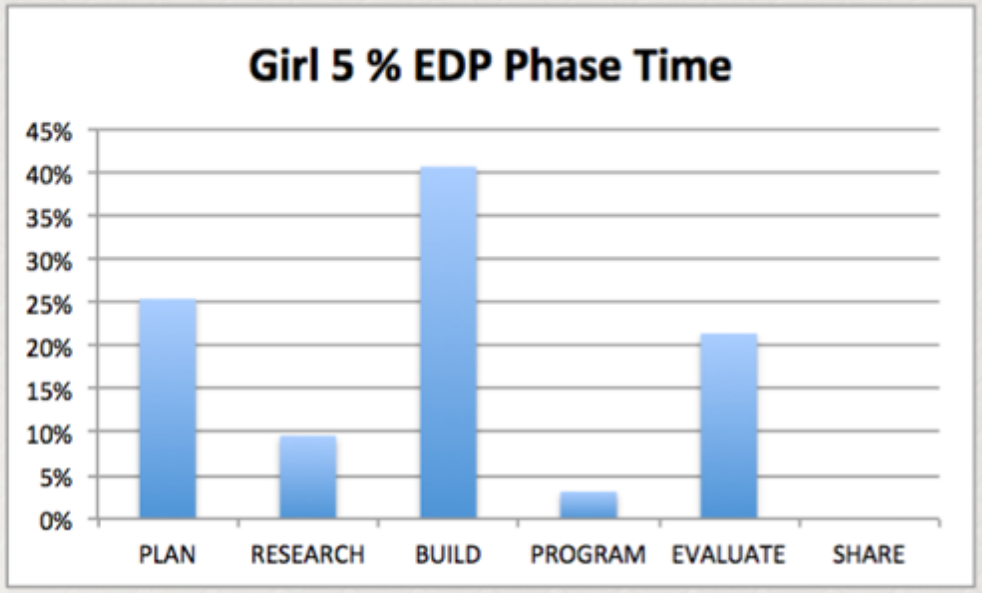


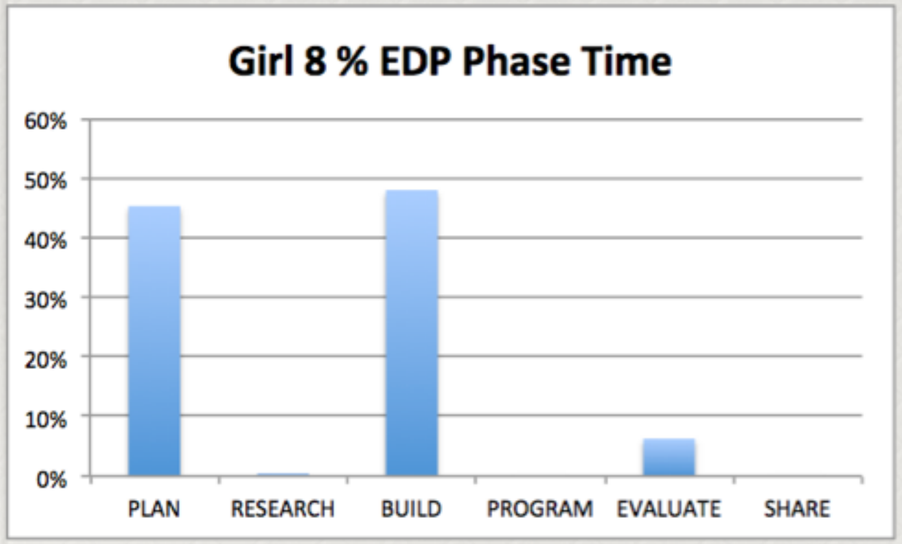
Boy 8 CF Example

Phase Data Conclusions

- *Total phase time most meaningful (avg. duration, frequency)*
- *Helps tell the story of the build*
- *2 typical patterns*
- *Outlier cases*

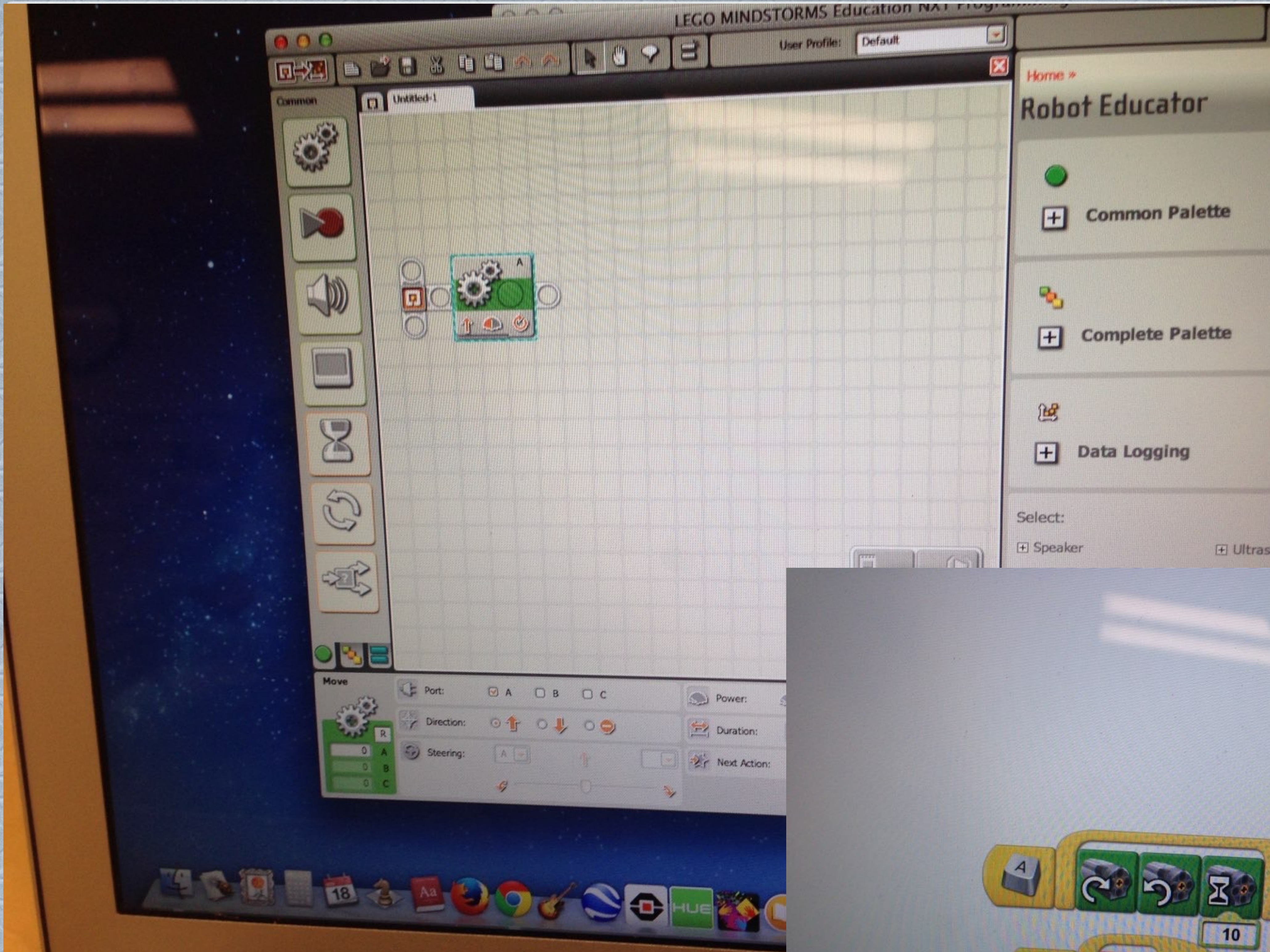


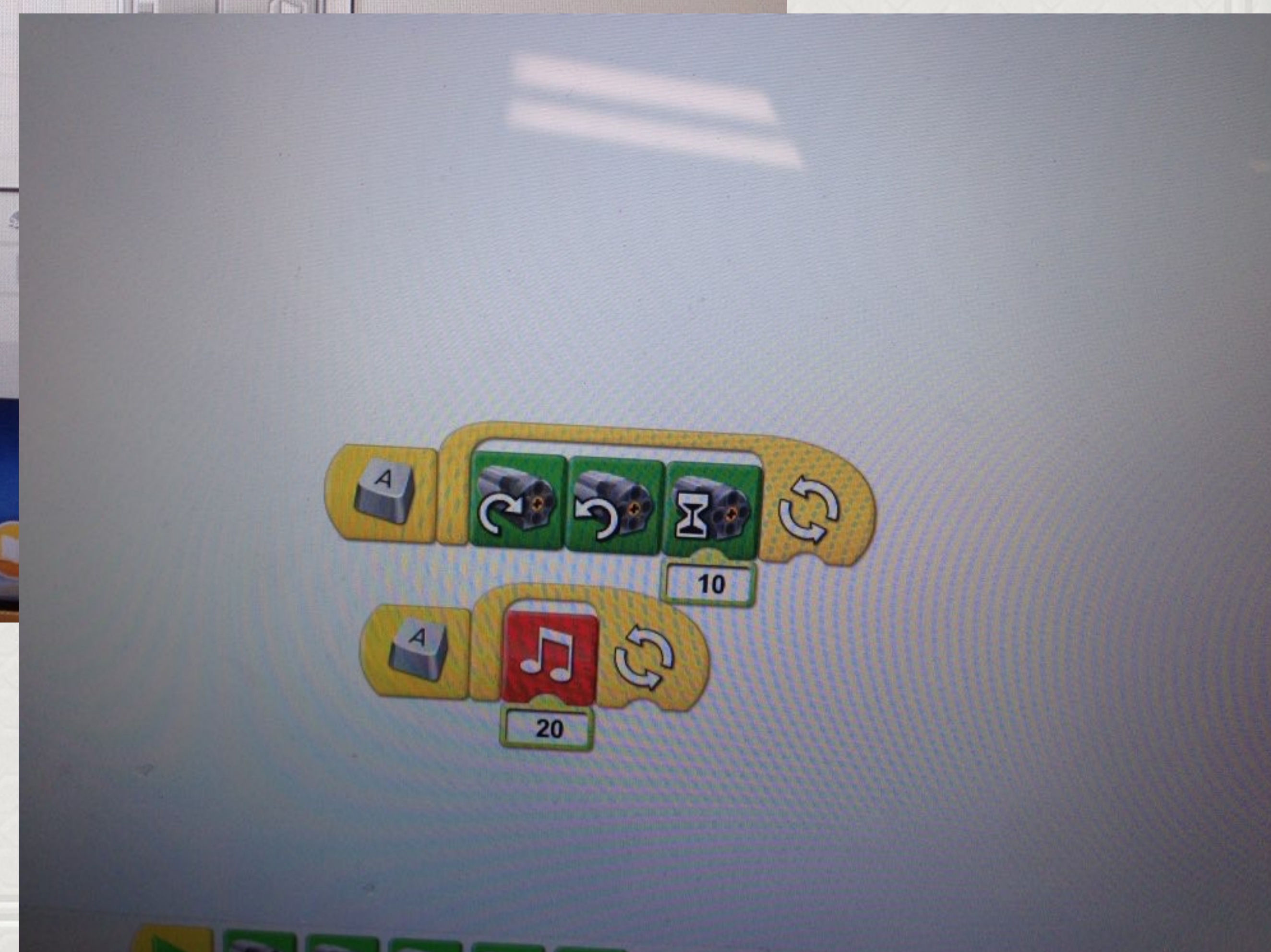




Other Results

- *Role of development - some role in executive function/causal reasoning and designerly play (G6 n=23, G2 n=61)*
- *Parts first versus idea first - tow different approaches, both could be used by students, Boy 4: "I'm just looking for parts to see if they give me any inspiration for something new."*
- *Sharing out side effect - caused reexamination, reworking of solutions.*
- *Prevalence of simultaneous EDP phases - BUILD and PLAN, for example. Varied by student.*
- *Transition rates - no pattern found unlike with college students (Atman et al., 2008, 2005)*
- *Role of imagination in filling in gaps - Girl 06: "I can do it when I'm drawing it."*
- *Role of teacher prompts - neutral teacher prompts caused significant learning moments (2 examples)*


LEGO MINDSTORMS Education
User Profile:
Default
Common
Untitled-1
Home »
Robot Educator
Common Palette
Complete Palette
Data Logging
Select:
Speaker
Move
Port:
A
B
C
Direction:
Steering:
Power:
Duration:
Next Action: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10
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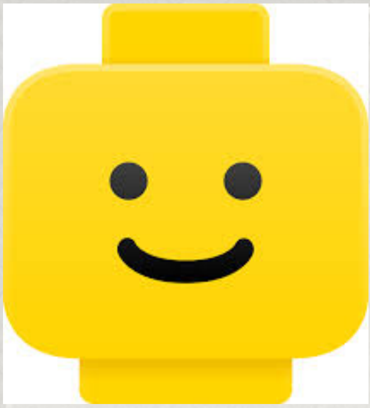

Implications for LEGO

- *Structural knowledge of LEGO connection (Constructopedia and instruction)*
- *Curriculum - executive function learning?*
- *Curriculum - domain specific process learning?*
- *Teachers (and curriculum designers) need to provide instruction and scaffolding for students in the application of: science and general problem solving, design processes knowledge, and design principles*

Future Research

- *Further analysis of subcodes and secondary codes*
- *Relative importance of and relationships between the different factors*
- *Segmenting data analysis*
- *Planning types - short and long term*

Summary

- *Differences in final designs and EDP not due to age or gender*
- *Identified seven key factors - executive function process (planning, causal reasoning, cognitive flexibility) domain specific process (design principles, EDP knowledge, and application of math and science) and structural knowledge*
- *Robotics a rich domain for important development that includes interpersonal, creative, cognitive, and domain specific*

Resources

- *johnsheffernan99@gmail.com*
- *Kids Engineer - http://www.kidsengineer.com/*
- *Elementary Engineering - Sustaining the Natural Engineering Instincts of Children*

DK Materials

- *Laminated data slides*
- *Laptop, adapter, European adapter, dongle*
- *Fixes - POV, etc missing, get to results faster, more selective individual builds?, minor fixes and cuts, explain first section more and relationship to coding and factors*